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Environmental Data for the White Oak Creek/White Oak Lake Watershed

C. B. Sherwood
J. M. Loar

Environmental Sciences Division
Publication No. 2779

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ENVIRONMENTAL SCIENCES DIVISION

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NUCLEAR AND CHEMICAL WASTE PROGRAMS
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ABSTRACT

SHERWOOD, C. B., and J. M. LOAR. 1986. Environmental data for the White Oak Creek/White Oak Lake watershed. ORNL/TM-10062. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 190 pp.

Oak Ridge National Laboratory (ORNL) is located in the White Oak Creek (WOC) watershed, which drains approximately 16.8 km^2 (6.5 $mile^2$). The waters of WOC are impounded by White Oak Dam at WOC's intersection with White Wing Road (State Route 95), 1.0 km (0.6 mile) upstream from the Clinch River. The resulting White Oak Lake (WOL) is a small, shallow impoundment, whose water level is controlled by a vertical sluice gate that remains in a fixed position during normal operations. White Oak Creek has been utilized for the discharge of treated and untreated wastes from routine operations since the Laboratory's inception. In addition, most of the more recent (1954 to date) liquid and solid low-level-waste disposal operations have been located in the drainage area of WOC. Sediments within the floodplain have sorbed the released chemical and radioactive contaminants and have subsequently accumulated in the lake bed. Under high-flow conditions these sediments can be carried over the dam and thus become a source of contaminant discharge to the Clinch River.

As a federally owned facility, ORNL is required to comply with all existing federal, state, and local environmental regulations regarding waste management (solid, liquid, and gaseous). On July 15, 1985, the U.S. Environmental Protection Agency published final rules to incorporate changes in the Resource Conservation and Recovery Act of 1976 that resulted from the passage of the Hazardous and Solid Waste Amendments of 1984. As a part of the rule changes, a new Sect. 3004(u) was added. The new section requires that any facility permit issued after November 8, 1984, include planned corrective actions for all continuing releases of hazardous waste or constituents from any disposal unit at the facility, regardless of when the waste was placed at the disposal unit.

This report was prepared to compile existing information on the content and quantity of hazardous substances (both radioactive and nonradioactive) in the WOC/WOL watershed and to provide background information on the geology, hydrology, and ecology of the site for use in planning future remedial actions.

1. INTRODUCTION

Oak Ridge National Laboratory (ORNL) is located in the White Oak Creek (WOC) watershed (Fig. 1). Since the inception of the Laboratory, WOC has been utilized for discharge of treated and untreated wastes from routine operations (Browder 1959). In addition, most of the recent (1954 to date) liquid and solid low-level waste (LLW) disposal operations have been located in the drainage area of WOC.

As a federally owned facility, ORNL is required to comply with all existing federal, state, and local environmental regulations regarding waste management (both solid, liquid, and gaseous). In response to these requirements, ORNL has established the Remedial Action Program to provide comprehensive management of areas where past research, development, and waste management activities have been conducted and have resulted in residual contamination of facilities or the environment.

On July 15, 1985, the U.S. Environmental Protection Agency (EPA) published final rules to incorporate changes in the Resource Conservation and Recovery Act of 1976 (RCRA) that resulted from the passage of the Hazardous and Solid Waste Amendments of 1984 (HSWA). As a part of the rule changes, a new Sect. 3004(u) was added. The new section requires that any facility permit issued after November 8, 1984, must include planned corrective actions for all releases of hazardous waste or constituents from any disposal unit at the facility, regardless of when the waste was placed at the disposal unit. When publishing this new rule, EPA stated that any solid waste management unit located at a facility required to obtain a post-closure permit or an operating permit will be subject to corrective action for continuing releases. A request for a permit for an ORNL hazardous waste management unit has been made, and as a result, it will be necessary to characterize WOC/WOL as well as other ORNL disposal units to determine if, and to what extent, corrective measures will be required to control releases.

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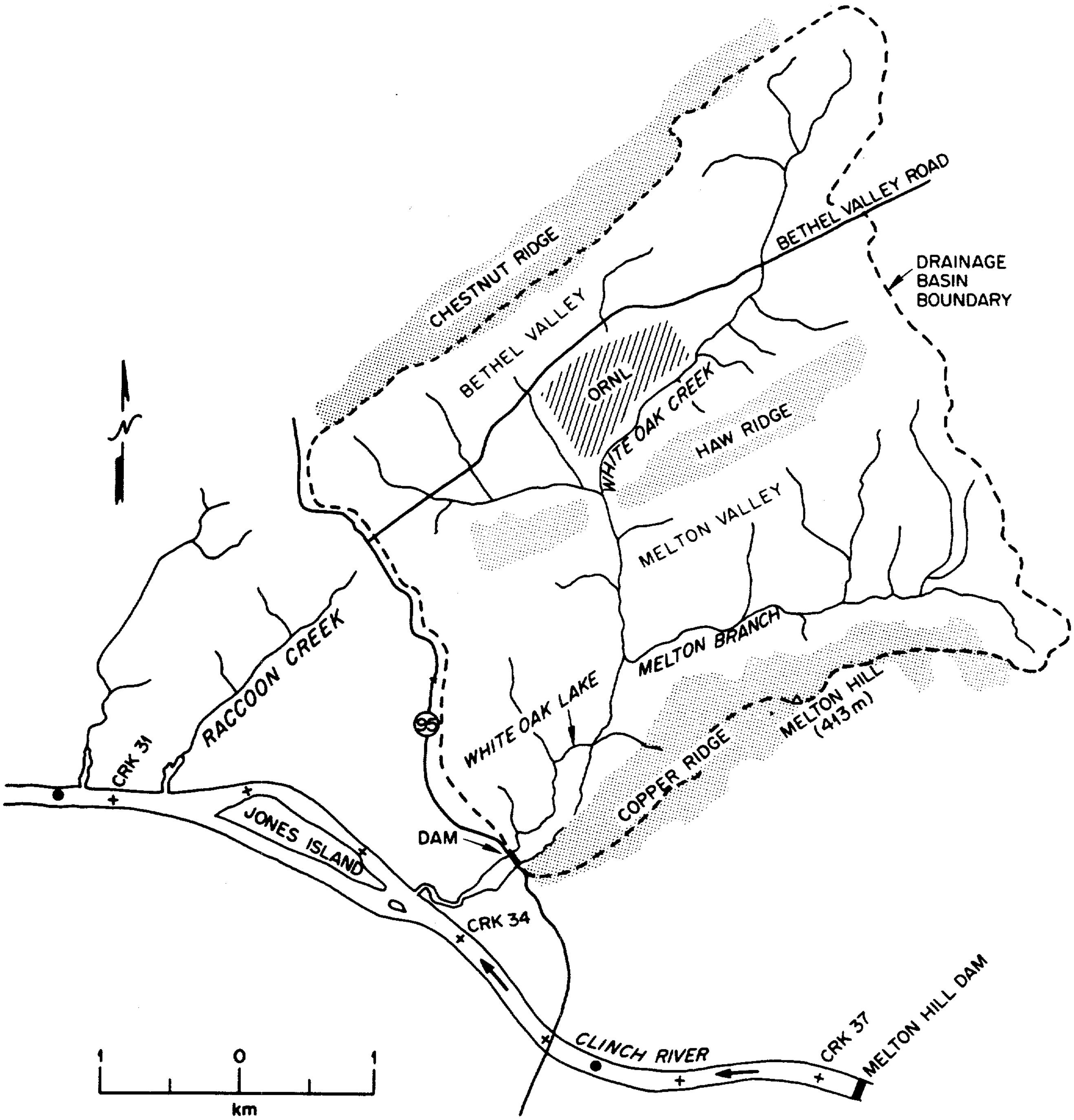

Fig. 1. White Oak Creek watershed.

As a first step in evaluating the need for corrective measures to control releases from WOC/WOL, a literature review was conducted to identify and evaluate the existing information on the content and quantity of hazardous substances involved, the potential sources of the contamination in the watershed, and previous data on site geology, hydrology, and ecology. Using this information, a plan was developed to define the additional information on geology, groundwater, surface water, soils and sediments, and biota necessary to support future analyses to meet regulatory requirements.

Background information on the WOC watershed was derived mainly from records and reports compiled by ORNL, the Tennessee Valley Authority, and the U.S. Geological Survey. In addition, previously unpublished information was supplied by a number of ORNL staff members. Appendix A represents a compilation of the information used in developing this report; additional detailed information on specific studies is available in the referenced documents. Although it was assumed in developing the characterization plan that data collection and analysis would be completed within a short time, the nature and magnitude of the contaminant sources indicate that hydrologic and ecologic monitoring should be continued on a long-term basis.

2. SITE DESCRIPTION

The WOC watershed drains much of Bethel and Melton valleys (which includes ORNL) to the Clinch River (Fig. 1). The waters of WOC are impounded by White Oak Dam (WOD) at WOC's intersection with White Wing Road (State Route 95) 1 km (0.6 mile) upstream from the Clinch River. The drainage areas upstream from the Clinch River and WOD are approximately 16.8 km^2 (6.5 $mile^2$) and 15.5 km^2 (6.0 $mile^2$), respectively (Martin Marietta Energy Systems, Inc., 1985).

The WOD was constructed in 1943 to form a holding basin for ORNL waste effluent. The dam is approximately 91.4 m (300 ft) long, 4.6 m (15 ft) high, and 10.7 m (35 ft) wide at its crest (Oakes et al. 1982). The location of WOD is 3.2 km (2.0 miles) north of Interstate 40 on Tennessee Highway 95 (Fig. 1). The dam is a low-head structure with a normal lake elevation of 227.1 m (745 ft) and is only 0.9 m (3 ft) above full-pool elevation in the Clinch River, which is 226.2 m (742 ft). Flow from WOL discharges through a weir and a concrete-box culvert to the lower reach of WOC. Modifications were made to the flow system at the dam in 1983 to increase the flood discharge capacity to 56.6 m^3/s (2000 ft^3/s), the estimated flow for a 100-year storm in the WOC watershed.

Water levels and flow in the WOC embayment are largely controlled by the operation of Melton Hill Dam 3.7 km (2.3 miles) upstream on the Clinch River, and Watts Bar Dam, which forms Watts Bar Reservoir about 94 km (58.8 miles) downstream on the Tennessee River. When the Watts Bar Reservoir is near full pool (approximately April to October), backwater from the Clinch River creates an embayment in WOC below the dam. In addition to the seasonal changes caused by the Watts Bar Reservoir, daily fluctuations in water levels and flow (including reversals) occur because of daily releases from Melton Hill Dam (Clinch River Study Steering Committee, 1967; Project Management Corporation, 1975).

In addition to natural drainage, the WOC watershed has received treated and untreated effluents from Laboratory activities since 1943.

Controlled releases include those from the Process Waste Treatment Plant, the Sewage Treatment Plant, and a variety of process waste holdup ponds scattered throughout the ORNL complex. The WOC also receives effluent from nonpoint sources such as Solid Waste Storage Areas (SWSAs) and LLW pits and trenches through both surface and groundwater flow (Fig. 2). Sediments within the watershed have sorbed the released chemical and radioactive contaminants and have subsequently accumulated in floodplain and lake bed areas. Under high-flow conditions these sediments can be carried over the dam and thus become a source of contaminant discharge to the Clinch River.

For planning and management purposes, the ORNL Remedial Action Program has subdivided ORNL and the immediate surroundings into Waste Area Groupings (WAGs). A WAG is defined as a geographic area that can be treated as a single hydrogeologic unit; however, in certain cases the WAG may contain a number of solid waste management units where past and current operations have resulted in the potential or known contamination of soils and/or groundwater. Figure 3 illustrates the suggested WAGs. It can be seen that the WOC watershed (WAG 2) is surrounded by a number of other potential contaminant sources represented by other WAGs. Other WAGs which represent contaminant inputs to WAG 2 will be characterized in other Remedial Action Program activities.

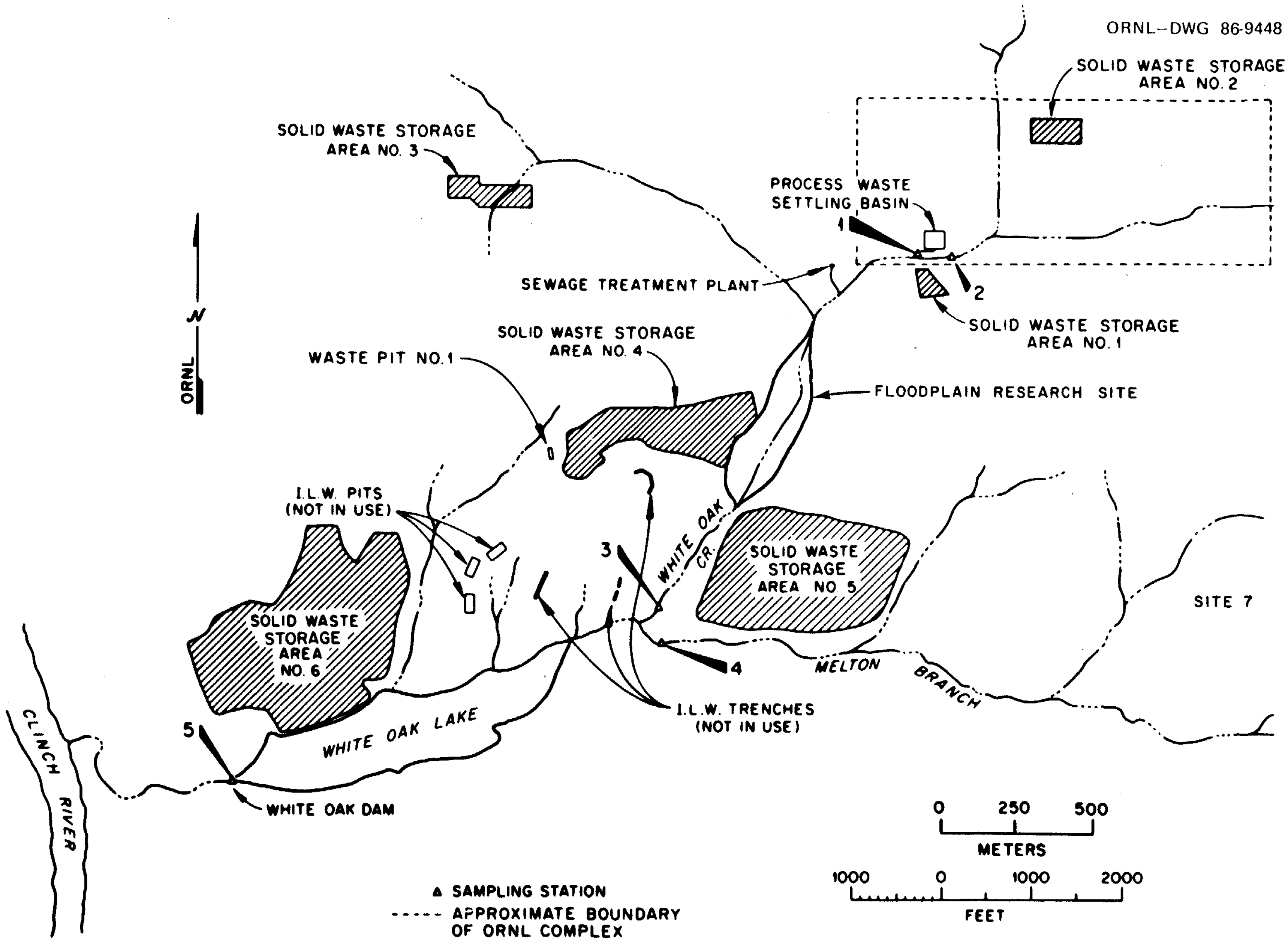

Fig. 2. Schematic of the White Oak Creek watershed showing potential sources of contaminants.

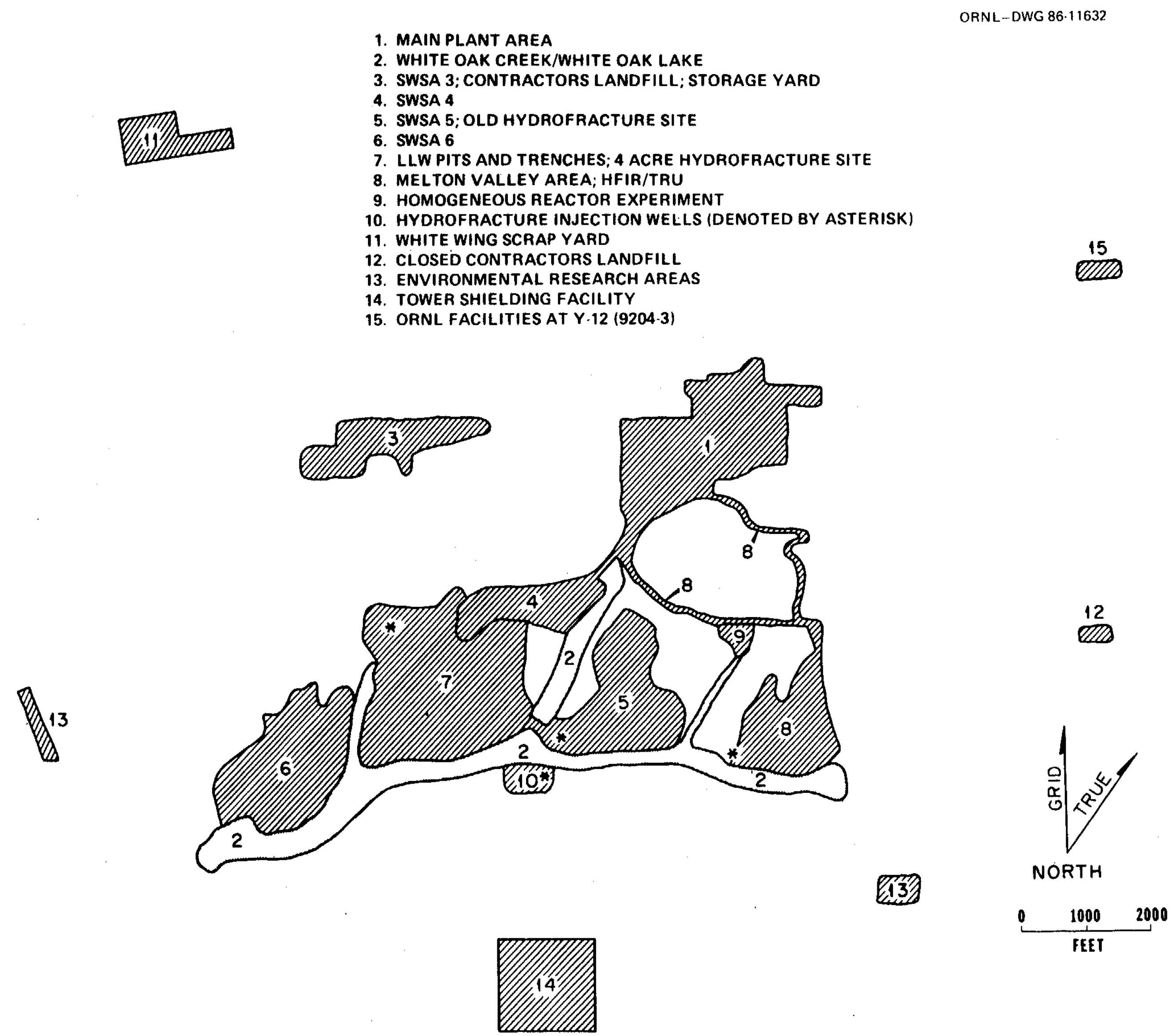

Fig. 3. Waste Area Groupings for ORNL.

3. STATUS OF SITE INFORMATION

Since WOL was created in 1943, a number of studies have been undertaken to determine contaminant sources, quantities of contaminants released and retained in the lake, and the geology and hydrogeology of WOC/WOL. Table 1 presents a summary of some of the more important studies that have been performed on WOC/WOL since 1945. In certain instances, the studies referenced in Table 1 represent summaries of the information developed; individual investigators have reported greater detail on their efforts in other reports and papers. The following sections summarize the findings of the earlier studies; more detailed descriptions of background data are provided in Appendix A.

3.1 CONTAMINANT SOURCES

White Oak Lake, created in 1943 by the construction of WOD, acts as the final holdup basin for liquid discharges prior to release into the Clinch River. For a short time during early ORNL operations (1943-1944), liquid wastes discharged to WOC were held up in an intermediate pond before being released to WOL. This pond was formed by an earthen dam across WOC near the present SWSA 4 site and was used for the settling of sediments, dilution, and decay of short-lived radionuclides. During this hold up, contaminated sediments accumulated within the basin area. In late 1944 this earthen dam failed and the intermediate pond was drained; however, most of the contaminated sediments were left in the floodplain area. The pond was never reconstructed. Estimates of the ^{137}Cs inventory in this floodplain site are on the order of 100 Ci. Following the failure of the dam at the intermediate pond, discharge of ORNL effluents continued into WOC and WOL. Contaminated sediments accumulated directly in the bed of WOL from 1944 to 1955 until the lake was drained. Starting in 1962, when WOD was again closed, additional sediments were deposited in the lake bed.

Since 1943, some 5×10^6 ft^3 of contaminated sediment has collected behind the dam. The sediment contains an estimated 650 Ci

Table 1. Summary of significant studies conducted in WOC/WOL 1943-1986

Year	References	Areas of investigation
1945-46	Cheka and Morgan (1947)	First reported data on sediments in WOL.
1950	Setter and Kochtitzky (1950)	Drainage areas and estimates of WOL capacity.
1948-52	Abee (1953)	Sediments in WOL.
1950-53	Krumholz (1954a, 1954b, 1954c)	Initial fish population and radioecological studies.
1956-58	Auerbach (1959)	68 shallow soil samples taken, soil mass estimated. Total ^{90}Sr content estimated. Agricultural plots established in former WOL bed.
1958	Lee and Auerbach (1959)	Radiation field above the drained WOL.
1961	Lomenick et al. (1961)	Sediments in WOL. Vertical and lateral distribution studied. Sediment discharge estimates in drained WOL.
1962	Lomenick et al. (1962)	^{106}Ru distribution in WOL sediments. Total ^{106}Ru content estimated.
1962	Lomenick et al. (1963)	Variation in radionuclide content of water and sediment with flow. 250 cores taken in lake bed. Measured thickness of sediments and radionuclide content. Cs inventory established.
1964	McMaster and Richardson (1969)	Ten sediment ranges. Vertical distribution of ^{106}Ru, ^{137}Cs, and ^{60}Co measured.
1965	Lomenick and Gardiner (1965)	Additional measurements of the vertical distribution of radionuclides in sediments. Vertical distribution of ^{137}Cs studied.
1969	Kolehmainen and Nelson (1969)	WOL radioecology studies.
1970	Tamura et al. (1970)	Sediment sampling in embayment.
1972	Blaylock et al. (1972)	Update of earlier assessment of radionuclides in WOL sediments.
1976	Webster (1976)	Hydrogeology of WOC/WOL.
1977	Blaylock and Frank (1979)	Tritium in sediments of WOL.
1978	Edgar (1978)	Flood discharge estimates.
1979	Cerling and Spalding (1981)	Analysis of streambed gravels for ^{60}Co, ^{90}Sr, and ^{137}Cs.
1979-80	Loar et al. (1981)	Comprehensive study of the aquatic ecology of WOC/WOL and the CR above and below the WOC embayment.
1982	Oakes et al. (1982)	History of WOL, sediments, water quality.
1984	MMES (1985)[1]	Environmental Monitoring Report. WOL sediment and water analyses.
1985	MMES (1986)[1]	Environmental Monitoring Report. WOL sediment and water analyses.
1985	Cerling (personal communication)	Update of 1979 streambed gravels survey.
1985	Synoptic ecological survey (this report, section 3.4.1.4)	Update results of the 1979-80 comprehensive survey.
1986	Blaylock et al. (In press)	Compilation of information on the radioecology of WOL.

[1]Martin Marietta Energy Systems, Inc.

of radioactivity, primarily ^{60}Co, ^{90}Sr, and ^{137}Cs (Oakes et al. 1982). In addition to the sediment activity, the water in the lake contains measurable quantities of ^{3}H and ^{90}Sr in solution, which is released through the monitoring station at WOD (Oakes et al. 1982). During periods of heavy rainfall, both waterborne radioactivity and contaminated sediment are released from the lake. Cesium-137 releases increase rapidly with flow due to the increased sediment transport, while ^{60}Co and ^{90}Sr (which are carried primarily in solution) increase to a lesser extent (Lomenick et al. 1963; Oakes et al. 1982).

A survey of streambed gravels for ^{60}Co, ^{90}Sr, and ^{137}Cs (Spaulding and Cerling 1979; Cerling and Spalding 1981) indicates the continuing contamination from sources in the watershed (Fig. 4). Sediments, rather than water, were selected for study because they concentrate dissolved metals and radionuclides from water.

The streambed surveys in 1979 and subsequent recent sampling at the same sites indicate that the most important source of ^{60}Co contamination is the High Flux Isotope Reactor (HFIR) facility, which is located on a tributary to Melton Branch (MB) in Melton Valley (Fig. 2). Figure 4(a) shows ^{60}Co concentration in gravel samples ranging from 1,000 to 10,000 dpm/g downstream from the HFIR site. There are also small but noteworthy concentrations of ^{60}Co in the two tributaries adjacent to the east end of SWSA 6.

The most important sources of ^{90}Sr are the ORNL plant complex, SWSA 4, SWSA 5, and the Homogeneous Reactor Experiment (HRE) facility on the MB tributary east of SWSA 5. Strontium-90 levels in the plant and SWSA 4 areas shown in Fig. 4(b) were over 100 dpm/g, and more recent samples in the HRE area were over 100 dpm/g. The high levels of ^{90}Sr shown in a WOC tributary in SWSA 6 in the 1981-82 results have decreased in subsequent samplings (Cerling, personal communication, 1986).

The most important sources of ^{137}Cs shown in Fig. 4(c) were the outfall from the process waste treatment plant in the laboratory area and the HRT facility on the MB tributary east of SWSA 5. Cesium-137 levels shown in Fig. 4(c) were 1,000 to 10,000 dpm/g; however, recent sampling in the SWSA 5 tributary shows decreasing ^{137}Cs levels.

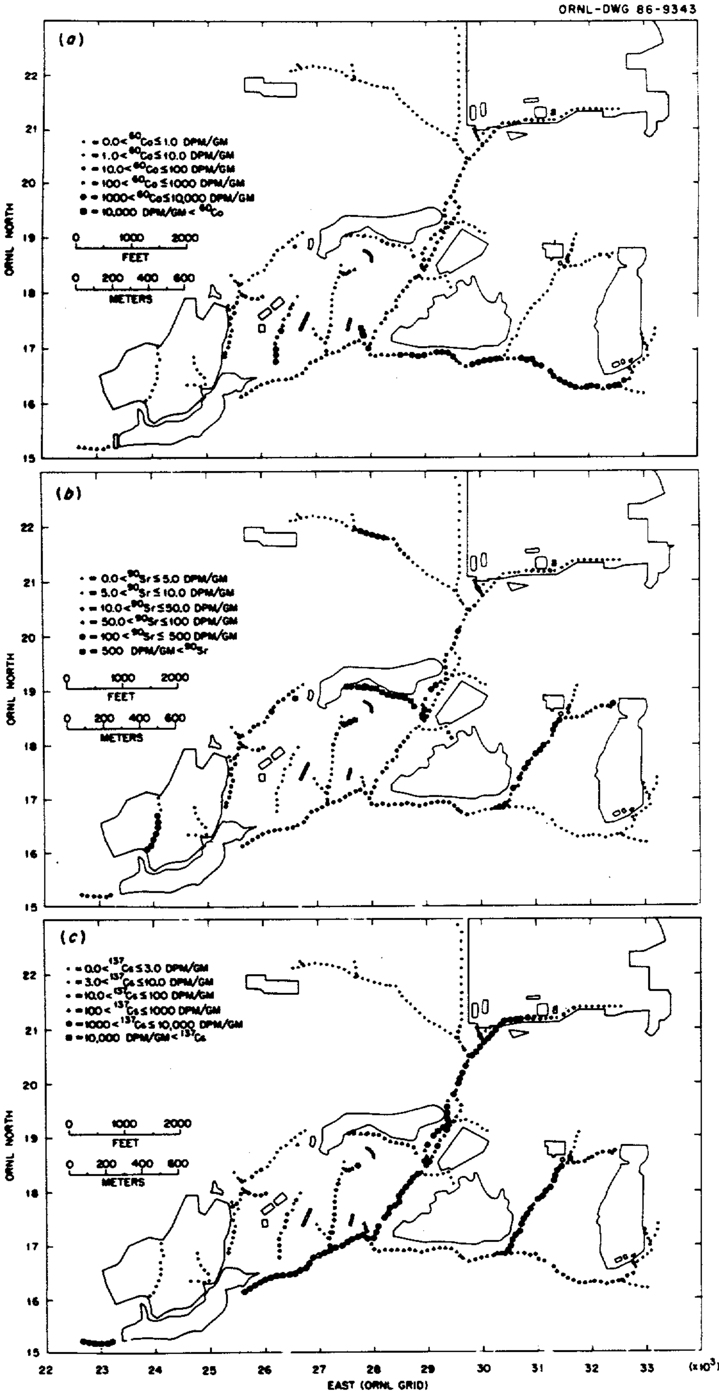

Fig. 4. Concentrations of radionuclides in sediment of White Oak Creek and its tributaries; (a) ^{60}Co, (b) ^{90}Sr, and (c) ^{137}Cs. Source: Cerling and Spaulding (1981).

3.2 GEOLOGY AND SOILS

The nature of the subsurface materials under the watershed was summarized in a review of hydrologic and geologic conditions by Webster (1976). Four major geologic units underlie the WOC drainage basin from northwest to southeast: the Knox Group of the Cambrian and Ordovician periods, the Chickamauga Limestone of the Ordovician period, and the Rome Formation and the Conasauga Group of the Cambrian period. The geologic units have been described by Stockdale (1951), McMaster (1963), and McMaster and Waller (1965); in addition, the Conasauga in Melton Valley has been mapped in detail by Barnett (1954).

The soils of the Oak Ridge area belong to the Entisols, Inseptisols, Alfisols, and Ultisols that are found extensively in the southeastern United States. Soils in these groups typically have developed under a forest canopy, and are characterized by being strongly leached and low in organic matter. The soils in the ORNL area are further characterized as silty, although considerable clay may be present, and acidic in reaction, with a pH from about 4.5 to 5.7 (Carroll 1961).

Two local soil characteristics of significance to waste disposal are the depth of weathering and type of clay developed. In areas underlain by the Chickamauga, the weathered zone is thin, commonly extending to a depth of less than 3 m (10 ft). In areas underlain by the Conasauga, the depth of weathering is related to topography, and may be described as thin in low-lying areas and thicker on the ridges. Studies of the Conasauga have reported that greatest permeability is associated with the transitional zone between the fresh and weathered rock. It is in this zone that the water table commonly occurs.

3.3 HYDROLOGY

3.3.1 Climate

The hydrologic characteristics of the WOC watershed are strongly influenced by the local climate. Among the climatic factors that establish the hydrologic features of the area are the amount and distribution of precipitation; the occurrence and distribution of snow and ice; and the effects of wind, temperature, and humidity on evapotranspiration and snowmelt (Linsley et al. 1975). Precipitation is probably the most important climatic factor to the flow system because it establishes the quantity and variations in runoff and streamflow as well as the replenishment to the groundwater system. Statistics on precipitation, temperature, humidity, and wind speed and direction are available for various periods of record at several stations in the vicinity of the watershed (Table 2) (Boegly et al. 1985). The closest long-term meteorlogical data (1947 to date) is available from the National Oceanic and Atmospheric Administration monitoring station in Oak Ridge about 16 km (9.6 miles) north of the center of the watershed. Monthly precipitation at the Engineered Test Facility (ETF) in SWSA 6 and at the Oak Ridge station for 1984-85 and the long-term mean at Oak Ridge are shown in Fig. 5.

The climate is classified as humid subtropical. The Cumberland Plateau to the northwest and the Smoky Mountains to the southwest tend to reduce the intensity of storm activity. Wind directions are highly conditioned by the ridge-valley topography; under normal weather conditions, up-valley winds come from the west-southwest during the daytime, and down-valley winds from the northeast are most common at night. These bidirectional trends correspond to unstable conditions caused by surface heating during the period from mid-morning until late afternoon (Rothschild et al. 1984a). Stable conditions occur at night and during overcast days (Davis et al. 1984).

3.3.2 Surface Water

3.3.2.1 White Oak Creek

White Oak Creek rises from springs in the Knox Formation on the southeast slopes of Chestnut Ridge, and with its tributary MB, drains areas in Bethel and Melton valleys to the Clinch River (Fig. 1). In addition to natural runoff and groundwater discharge, the creek receives the treated and untreated process waste water, treated sanitary sewage effluent, and reactor cooling water from the laboratory facilities (Fig 2). This water is obtained from outside the watershed and it represents a significant fraction of the annual streamflow.

Table 2. Meteorological stations in the vicinity of SWSA 6[a]

Station description	Location	Period of record	Measurements
Knoxville[b]	McGhee Tyson Airport	1942-present	Precipitation
		1942-present	Wind
		1942-present	Temperature
		1942-present	Temp. gradient
		1942-present	Humidity
Oak Ridge	City	1947-present	Precipitation
		1947-1979	Wind
		1947-present	Temperature
		1947-present	Temp. gradient
ORNL Towers A & B	ORNL	1982-present	Precipitation
		1982-present	Wind
		1982-present	Temperature
		1982-present	Temp. gradient
ORNL Tower C	ORNL	1982-present	Precipitation
		1982-present	Wind
		1982-present	Temperature
		1982-present	Temp. gradient
		1982-present	Humidity
		1982-present	Solar radiation
USGS[c]	SWSA-5	1975-present	Precipitation[d]
USGS[c]	SWSA-6	1976-present	Precipitation[d]
ETF	SWSA-6	1980-present	Precipitation[d]
EPICOR[e]	SWSA-6	1985-present	Precipitation
		1985-present	Wind
		1985-present	Temperature
		1985-present	Humidity
SW7	Proposed SWSA 7	1984-present	Precipitation
Bldg. 1505	ORNL	1984-present	Solar radiation

[a]At various times, meteorological measurements have been made at the Y-12 plant, K-25, an early X-10 station, and the tower shielding facility (ORO-99).

[b]Measurements also exist for the period 1871 till the station was moved to McGhee-Tyson.

[c]U.S. Geological Survey.

[d]Precipitation gauges are not equipped to measure snowfall.

[e]Ion exchange resin leaching site.

Source: Boegly et al. 1985.

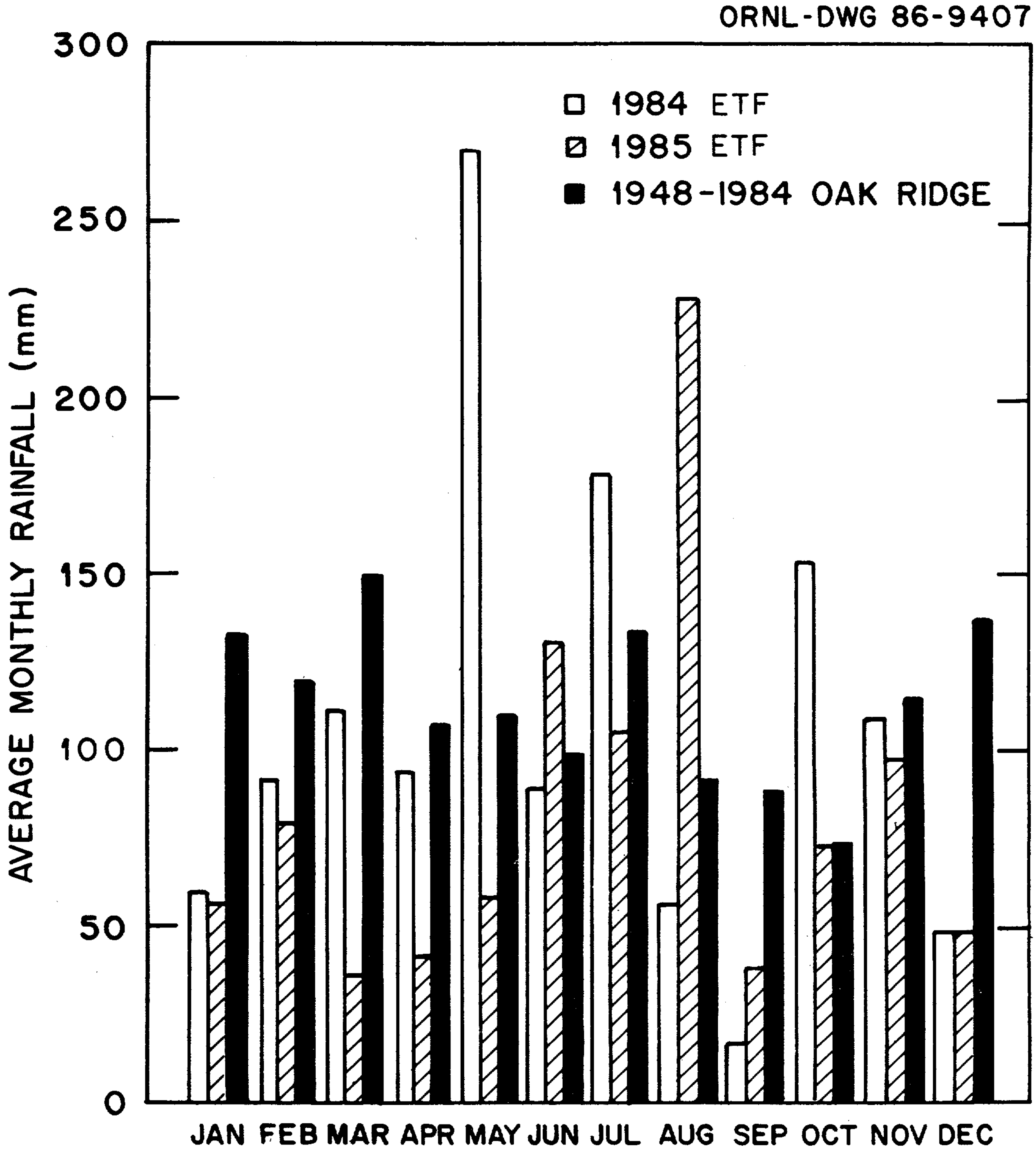

Fig. 5. Monthly rainfall for the Engineered Test Facility (ETF) site, 1984 and 1985.

Flow in the creek is controlled about 1 km (0.6 mile) upstream from the Clinch River by WOD. Flow at WOD has been monitored since the early 1950s; however, measurement of flows greater than 4.2 m^3/s (150 ft^3/s) at the dam were hampered by the nature and level of the sluice gate until late 1983, when new weirs and automatic recording equipment were installed.

As part of a recent ORNL project to upgrade the stream monitoring stations at MB, WOC, and WOD, new weirs, equipment shelters, and monitoring and sampling equipment were installed in late 1983. The flow at the weirs is measured with an ultrasonic flow meter that contains a microprocessor to translate weir water level to flow proportional control for the water sampler. At each of the stations, equipment was installed to provide water sampling proportional to streamflow. To establish the radiation levels of the water effluent, new gross beta and gamma radiation monitoring equipment was installed. In addition, a robot monitor is used to continuously monitor the following parameters: pH, dissolved oxygen, turbidity, conductivity, and temperature. The robot monitor is a modular, automatic water quality data acquisition system capable of meeting National Pollutant Discharge Elimination System (NPDES) requirements (Martin Marietta Energy Systems, Inc. 1985).

3.3.2.2 White Oak Lake

White Oak Lake is a small, shallow impoundment that functions as a final settling basin for waste effluents discharged to the lake via WOC, MB, and other smaller streams. The accumulation of sediment over the years has altered the environment of WOL. Except in the creek channel near the east shore where the substrate is mostly small rubble and gravel, the lake bottom consists primarily of silt, clay, and organic matter (Loar et al. 1981). The average annual rate of sediment accumulation prior to 1953 was estimated to be 2832 m^3 (100,000 ft^3), or about 2 cm/year (Loar et al. 1981).

Because the lake is small and shallow, the water retention time is very short. Based on the average annual inflow, the retention time has been estimated to be approximately 2 d when the lake is empty and the gate in WOD is set at 227.1 m (745 ft), but less than 24 h under normal conditions when the gate elevation is 226.2 m (742 ft) (D. D. Huff, ORNL, unpublished data). During major storm events when retention time is minimal, large quantities of sediment can be transported through the watershed to the Clinch River (Edgar 1978). Even relatively small storms can result in dramatic reductions in Secchi disk transparency (Loar et al. 1981).

3.3.2.3 Chemical Quality

The chemical quality of WOC upstream from the laboratory resembles that of groundwater in Bethel Valley (Webster 1976). At WOD the water reflects the many man-made influences on the creek and tributaries in Bethel and Melton valleys, as well as the beneficial effects of WOL.

The effects of plant operations on water quality in the creek and lake have been studied since the early 1940s. Continuous-flow proportional sampling at WOD was initiated in the late 1940s to provide a means of evaluating the amount of radioactivity entering the Clinch River. Calculations of the levels of radionuclides in the Clinch River can be made by use of the concentrations and flow measured at WOD and the dilution provided by the river. The mean annual dilution factor at the junction of WOC and the River has been calculated as about 390 for the period 1951-60 (Carrigan 1968) and 375 for the period 1962-73 (Webster 1976).

Major variations in the long-term levels and types of radionuclides discharged through WOD were caused by changes in the source of the radioactivity as well as by improvement in plant operations. As described by Webster (1976), much of the radioactivity shown for the early 1960s came from the seepage pits into which intermediate-level liquid wastes were discharged. A much smaller amount of activity originated at the wastewater treatment plant and from accidental releases of activity discharged into that system. While some of the activity may have come from the burial grounds, the concentrations are thought to have been sufficiently small that they could not be differentiated from the larger concentrations already in the stream (Lomenick and Cowser 1961). During the 1960s a significant decrease in contaminant release was effected. The reduction was accomplished largely by discontinuance of the pits (and later, the trenches) and by improvements in the treatment of Laboratory effluent. In recent years ^{3}H (tritium) and ^{90}Sr (strontium) have been the principal contaminants in the discharge. These two nuclides are of interest because nearly all of the tritium and a part of the strontium are believed to emanate from the solid waste burial grounds.

As part of the current ORNL operations and environmental monitoring network, flow is monitored for radioactivity at WOD and at eight sites in WOC and its tributaries (Fig. 6). Flow proportional samples are collected weekly for laboratory analysis at the dam, at five of the stream monitoring sites, and at three additional sites related to leachate from SWSAs 5 and 6 and the LLW pits as shown in Fig. 6. In addition, plant effluent is monitored and sampled at four sites before it enters tributaries of WOC. Flow is also monitored and sampled at the Melton Hill Dam on the Clinch River, 3.7 km (2.3 mile) upstream from the confluence of WOC and the Clinch River, and two sampling stations have been maintained in the CR below the junction of the Clinch River and WOC (CRK 33.5, CRM 20.8). These sampling station are at the Oak Ridge Gaseous Diffusion Plant (ORGDP) water intake, Clinch River Kilometer (CRK) 23.3, [Clinch River Mile (CRM) 14.5], and Center's Ferry near Kingston, Tennessee, (CRK 7.2, CRM 4.5) (Oakes et al. 1982).

Four of the sampling sites included above are NPDES ambient monitoring stations: WOD (Station 5), WOC (Station 3), MB (Station 4), and the sewage treatment plant (STP). The NPDES permits were issued by EPA for each of the Oak Ridge facilities in 1975. The permits established a number of discharge locations at each installation and listed specific concentration limits and/or monitoring requirements for a number of parameters at each discharge location. Table 3 lists the discharge locations at ORNL, the parameters at each location for which limits have been established, and the permit limits for each parameter.

ORNL-DWG 78-16246R2

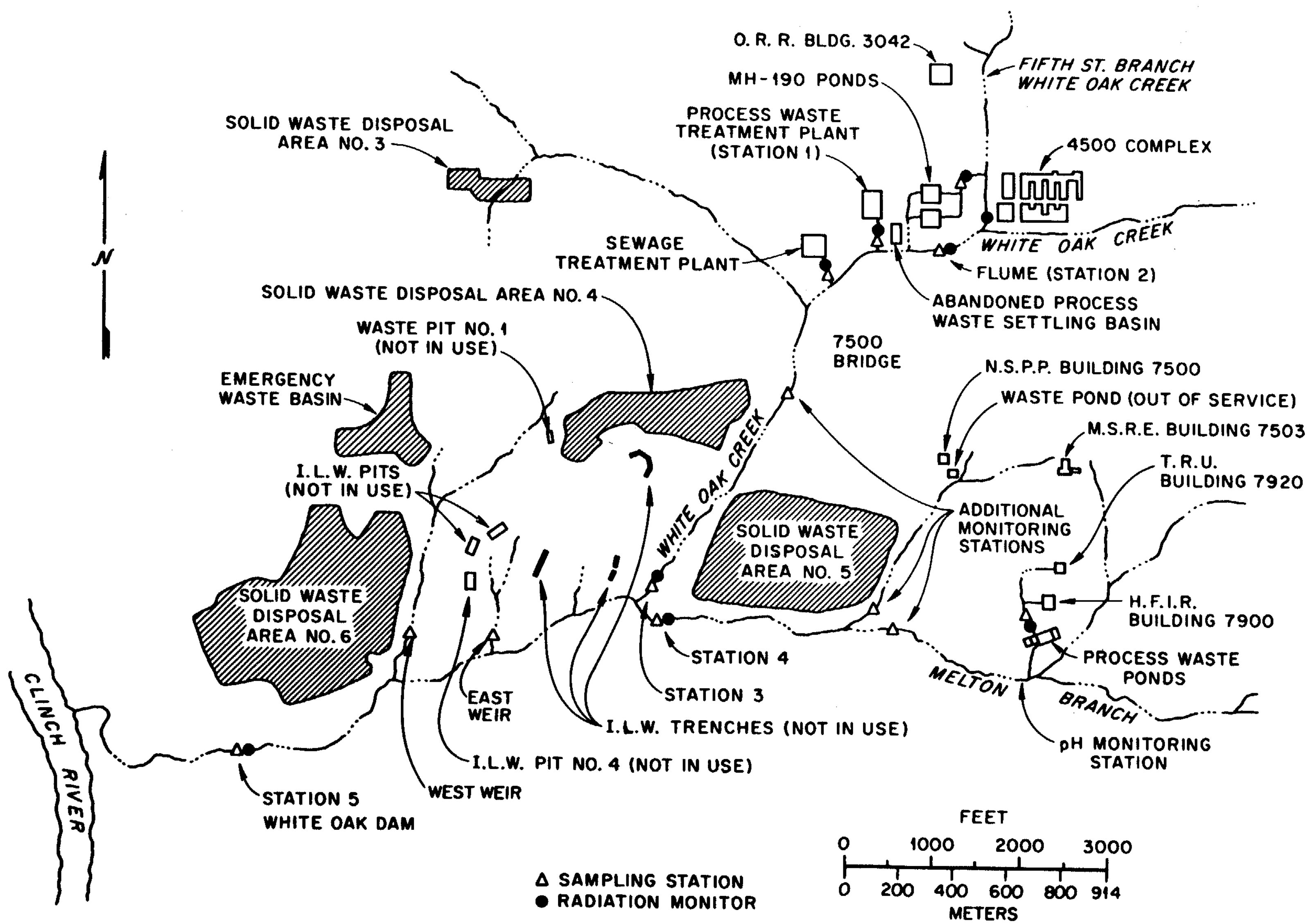

Fig. 6. Location plan for White Oak Creek sampling stations and radiation monitors.

Table 3. 1984 National Pollutant Discharge Elimination System (NPDES) requirements for ORNL

Discharge point	Effluent parameters	Effluent limits: Daily average (mg/L)	Effluent limits: Daily maximum (mg/L)	Percentage of measurements in compliance
001 (White Oak Creek)	Dissolved oxygen	5[a]		99
	Dissolved solids		2000	100
	Oil and grease	10	15	100
	Total chromium		0.05	100
	pH, units		6.0-9.0	100
002 (Melton Branch)	Total chromium		0.05	100
	Dissolved solids		2000	100
	Oil and grease	10	15	100
	pH, units		6.0-9.0	100
003 (Sewage treatment plant)	Ammonia (as N)		5	54
	BOD		20	90
	Residual chlorine		0.5-2.0	94
	Fecal coliform, No./100 mL	200[b]	400[c]	100
	pH, units		6.0-9.0	100
	Suspended solids		30	94
	Settleable solids, mL/L		0.5	96

[a]Minimum.
[b]Monthly average.
[c]Weekly average.

Source: Martin Marietta Energy Systems, Inc. 1985.

Trends in discharges of ^{90}Sr and ^{3}H to the Clinch River are presented in Fig. 7. These are the principal contributors of radioactivity in terms of total curies discharged. Total curie amounts for the two radionuclides appeared to increase in 1984 compared with 1983--about 14% for ^{3}H and 20% for ^{90}Sr. The annual variations in the discharges from WOL are generally a function of the variability in annual precipitation patterns. The 1984 discharge continues to reflect an increase in the total curies discharged over WOD, beginning in 1980 after a significant decrease from 1979 levels. Some of the apparent increase in 1984 may result from improved accuracy in high-flow readings. New weirs and associated flow instrumentation were made operational in early 1984 (Martin Marietta Energy Systems, Inc. 1985).

Analysis of water samples collected at the confluence of WOC and the Clinch River showed that ^{90}Sr and ^{3}H concentrations were significantly less than those measured at WOD, ^{60}Co was the same, and ^{137}Cs was higher (Martin Marietta Energy Systems, Inc. 1985). Concentrations at this confluence point are dependent on the relative levels and flows of the creek and river, in addition to the quantity of activity being discharged from WOD. Concentrations determined at the Clinch River sampling stations downstream from the confluence of WOC and the River showed a marked decrease for all measured radionuclides, many of which were below analytical detection limits (Martin Marietta Energy Systems, Inc. 1985).

Concentrations of nonradioactive chemicals in samples collected at WOD for analysis during 1984 are shown in Table 4. Concentrations may be compared with Tennessee's instream allowable concentrations that are based on the long-term protection of domestic water supply, fish and aquatic life, and recreation classifications (Martin Marietta Energy Systems, Inc. 1985).

3.3.2.4 Radioactivity in Sediments

Radioactivity in sediments in WOC and WOL have been studied since the mid-1940s. Studies conducted from 1945 to 1979 are summarized in considerable detail in a historical review by Oakes et al. (1982). Selected sediment data are included in Appendix A.

ORNL-DWG 86-12226

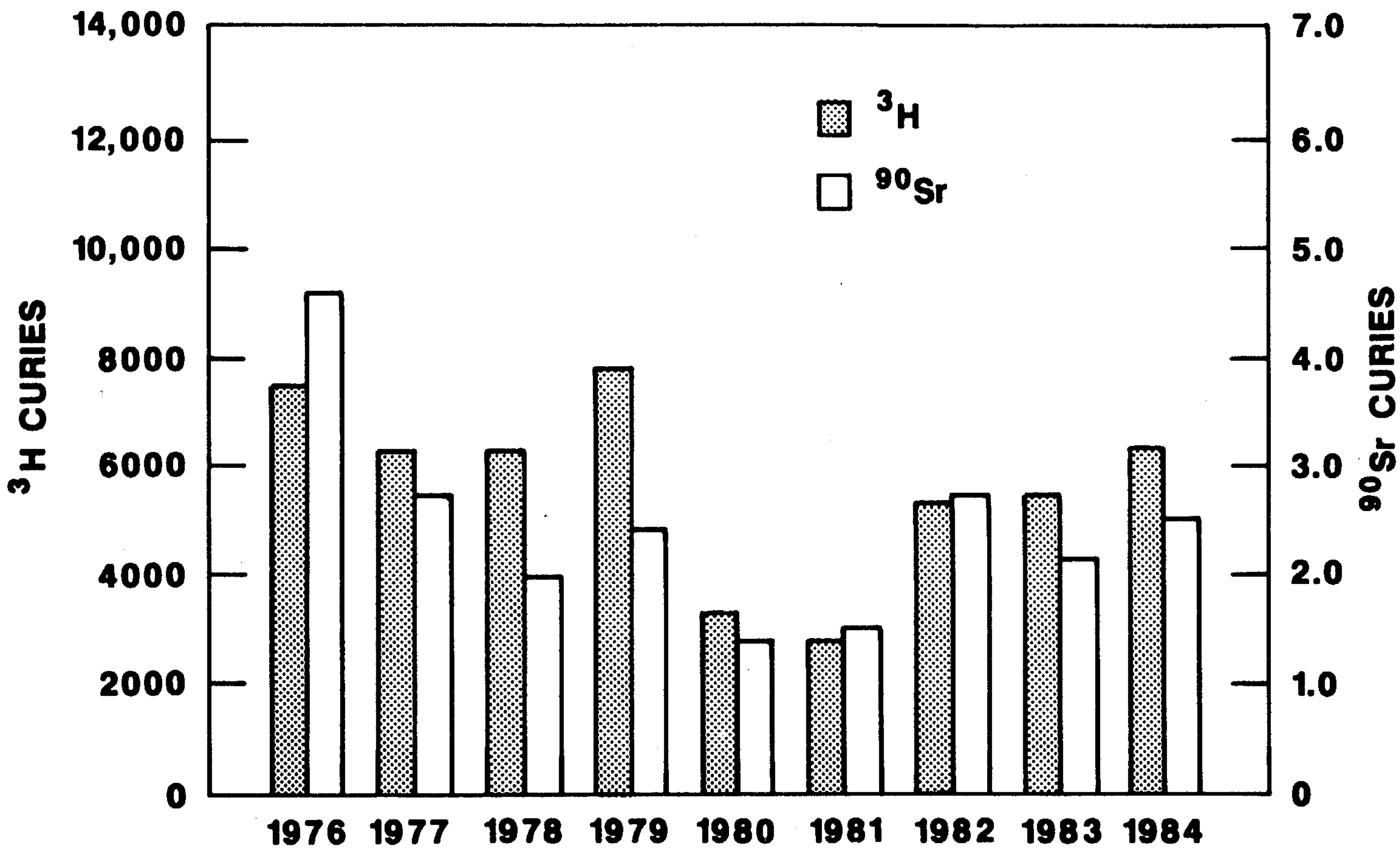

Fig. 7. Curies discharged over White Oak Dam. Note: multiplying the concentrations by 3.7×10^{10} will convert curies (Ci) to becquerels (Bq).

Table 4. 1984 Concentrations of chemicals in water collected at White Oak Dam

Chemical	No. of samples	Concentration (mg/L)				
		Max	Min	Av	95% CC[a]	Criteria[b]
Cr	12	0.025	<0.01	<0.011	0.0025	0.05
Zn	12	0.036	<0.02	<0.024	0.0034	0.05
NO_3(N)	12	7.2	0.4	4.1	1.2	10
Hg	12	0.0002	<0.00005	<0.0001	0.00004	0.00005

[a]95% confidence coefficient about the average.

[b]Tennessee stream standards based on protection of domestic water supply, fish and aquatic life, and recreation classifications.

Source: Martin Marietta Energy Systems, Inc. 1985.

3.3.3 Groundwater

3.3.3.1 Occurrence

Groundwater occurs in all four formations which underlie the WOC basin. The dolomite of the Knox Group on Chestnut Ridge and the Chickamauga Limestone underlying Bethel Valley are the principal water-bearing units. The Rome Formation on Haw Ridge and the Conasauga Group underlying Bethel Valley are thought to contain only small quantities of water. Water occurs in the weathered rock of all of the units. The primary porosity of the formations is quite low; thus, the secondary porosity (though also low) controls most groundwater flow below the weathered zone.

The groundwater reservoir in the basin is replenished by the infiltration of precipitation through the surficial materials to the water table. Recharge is also received from WOC when the creek level is above the water table and from ORNL waste ponds. Groundwater flows downgradient to points of discharge such as springs or seeps and WOC or its tributaries. Major losses occur by evaporation or transpiration near ground surface. There is little or no discharge from wells for water supply in the basin.

The depth to the water table varies both with location and time. Measured depths range from as little as 0.3 m (1 ft) in low areas near streams or ponds to as much as 20.4 m (67 ft) under hills or ridges. The water table fluctuates with recharge and discharge during the year from high levels during January through March to low levels during September and October, with declines ranging from 0.3 m (1 ft) in drainage areas to as much as 4.6 m (15 ft) under hillsides (Webster 1976).

Water table contour maps for the entire watershed are not available; however, maps for SWSAs 3, 5, 6, and the pits and trenches area have been prepared. These maps indicate that the water table generally follows the topography of the land surfaces but in a subdued fashion. Although a large number of observation and test wells have been drilled in the watershed during past studies, few of these wells are located in the flood plain of WOC and WOL.

3.3.3.2 Movement

In an unconfined, permeable aquifer groundwater moves downgradient by gravity in a direction normal to the water table contours. In this area, these conditions generally exist chiefly in the zone of weathered rock near land surface. In the underlying strata, flow is downgradient but the direction of movement is most strongly influenced by directional differences in permeability caused by the complex nature of the materials and local bedding, solution channels, and fracture and joint systems. Thus, groundwater movement above bedrock in the watershed may be expected to be toward and into the surface drainage network, whereas the direction of flow at depth may be controlled by the alignment and degree of interconnection of the joints and cavities in the rock and thus have little or no relationship to the direction of movement indicated by water table contours (Webster 1976).

Flow in the Conasauga Group underlying Melton Valley is complicated by the impermeable nature of the rocks and the extensive displacement and deformation of these materials by past geologic action (Webster 1976). Boegly (1984; Boegly et al. 1985) has recently reviewed the information available from a number of reports on the hydrogeology of SWSA 6 in the lower White Oak area in Melton Valley. This information indicates, in general, that flow in the Conasauga is associated with bedding planes, joints, faults, folds, and fractures, some of which are slightly enlarged as a result of the dissolution of carbonate. Transmissivity is greatest parallel to geologic strike (Webster 1976), suggesting that preferred flowpaths are associated with a strike-joint set described by Sledz and Huff (1981) or with the intersections of bedding planes with the strike-joint set (Smith and Vaughan 1985b). Small-scale folds and faults formed during regional geologic deformation have also been found to be zones of unusually high transmissivity that act as conduits for groundwater flow and contaminant transport parallel to geologic strike (Olsen et al. 1983; Rothschild et al. 1984a; Smith and Vaughan 1985a) and may form local impediments to flow perpendicular to strike (Olsen et al. 1983).

3.3.3.3 Aquifer Properties

The hydraulic properties of the subsurface materials must be known in order to assess the movement of groundwater and possible contaminants through the formations underlying WOC and WOL. These properties include hydraulic conductivity, transmissivity, (hydraulic conductivity times aquifer thickness), storage coefficient, porosity, dispersivity, and the heterogeneity of the flow system. In general, the Conasauga Group is locally heterogeneous, both lithologically and as an aquifer. The primary porosity of the group is quite low; therefore, the secondary porosity (fracture system) controls groundwater flow in the subsurface.

In the Conasauga Group, the actual thickness of the aquifer(s) is difficult to define. The aquifer is continuous from near-surface materials (weathered rock) to great depth. A decrease in aquifer permeability with depth appears to be present, but there is no clear-cut boundary between permeable and impermeable strata. The differences between weathered and unweathered rock are not great enough to designate them as separate aquifers. The general decrease in permeability with depth is probably a result of a combination of two factors: (1) the effect of weathering decreases with depth and (2) the number and extent of unhealed fractures decreases with depth. At depth, individual structures are likely to control the subsurface movement of water in contrast to the pervasive joint system found nearer to the ground surface (Rothschild et al. 1984a). Water-level data collected in a brecciated zone in the Maryville Limestone underlying the ETF site may indicate the existence of semi-independent confined aquifers at depth in the formation.

A summary of the major aquifer characteristics estimated for the ETF site is given in Table 5. These parameter values provide a basis for assessing groundwater and solute movement under the ETF site and provide a general indication of the characteristics of the aquifer underlying the lower WOC watershed.

Table 5. Summary of Engineered Test Facility Aquifer Characteristics

Method	Parameter	Value
Tracer test	Average linear velocity	0.17 m/d
Pump test	Transmissivity (T)	1.25×10^{-3} to $4.36 \times 10^{-3} m^2/min$
	Storage coefficient (S)	5×10^{-4} to 0.01
Well slug test	Hydraulic conductivity (K)	$6.31 \times 10^{-5} cm/s$
Darcy equation	Effective porosity (Θ)	0.03
	Effective aquifer thickness	67 m

Source: Davis et al. 1984.

3.3.3.4 Chemical Quality

Groundwater in the WOC watershed is of a calcium bicarbonate type with a pH usually between 7 and 8, reflecting the effects of the limestone and dolomitic materials through which the water has moved (Webster 1976). Radionuclide analyses of water samples from ETF and the proposed SWSA site in Melton Valley are at or near background levels (Davis et al. 1984, Rothschild et al. 1984a).

Groundwater quality has been greatly affected by leachates in the vicinity of solid and liquid waste disposal areas. However, the available studies indicate that the migration of leachate in groundwater has been limited to relatively short distances from the source or to nearby seeps or streams.

3.4 ECOLOGY

Many studies of the aquatic and terrestrial ecology of the watershed and WOL have been conducted over the past 35 years. Many of the earlier studies focused on the radioecological effects of ORNL effluent discharges to WOL; other studies were actually surveys that described the biotic communities in the watershed. Although both types of studies are reviewed below, detailed descriptions of the aquatic and terrestrial communities are not presented. Such information is readily available from the references cited in the text.

3.4.1 Aquatic Ecology

3.4.1.1 Radioecology of White Oak Lake

Numerous studies have been conducted on the accumulation of radionuclides by fish in WOL. With the exception of the ORNL monitoring program which is conducted in the WOC embayment and the Clinch River (Martin Marietta Energy Systems, Inc. 1985), and a study of the distribution of tritium (Blaylock and Frank 1979), most of these investigations were conducted in the late 1960s and early 1970s. A summary of these studies can be found in Oakes et al (1982) and Blaylock et al. (in preparation).

The influence of trophic level on the concentration of ^{137}Cs, ^{60}Co, and ^{90}Sr was determined for five species of fish in WOL by Kevern and Griffith (1966). No correlation was found between trophic level and radionuclide concentration. A comprehensive study on the cycling of ^{137}Cs in bluegill was carried out by Kolehmainen and Nelson (1969). Results indicated that the concentration of ^{137}Cs increased linearly with size up to 70 g. A seasonal variation in the ^{137}Cs level in bluegill was observed, with the maximum concentration occurring in February and the minimum concentration occurring in August. Concentrations of ^{137}Cs in other fish species were also determined, and all species displayed a seasonal cycle similar to bluegill.

Investigations of the accumulation of radionuclides in bluegill, gizzard shad, and goldfish, and of the feeding habits of those fish in WOL, were conducted by Nelson et al. (1970). Fish were collected monthly from WOL from April 1969 to May 1970. Cesium-137 and ^{60}Co were consistently found in the fish. Ruthenium-106, ^{125}Sb, and ^{65}Zr occurred in small quantities in all three species, but the contribution of these three radionuclides to the body burden of the fish was insignificant.

Other radionuclides have been found at very low concentrations in fish in WOL. Eyman and Trabalka (1980) determined that the concentration of $^{239,240}Pu$ in bluegill, goldfish, shad, and largemouth bass ranged from 2×10^{-4} to 1×10^{-3} pCi/g fresh wt. The concentrations of tritium in algae, aquatic plants, benthic invertebrates, and fish were usually less than the concentration in the lake water, which ranged from 403 to 646 pCi/mL in 1978 (Blaylock and Frank 1979).

<u>Effects of radiation on aquatic biota</u>

Organisms inhabiting WOL are irradiated not only from external sources in water and sediment, but also from internal sources as a result of consuming food that has accumulated radionuclides from an environment contaminated with significantly higher-than-background levels of radionuclides. In addition to the potential effect that radiation could have on the natural populations of organisms inhabiting WOL, a pathway exists for the transfer of radionuclides through the aquatic food chain to humans by the consumption of fish.

One of the earliest ecological studies of WOL and WOC was a survey for the purpose of determining the radioactivity in the biota and to document the effect on survival rates, population balances, and types of organisms that were affected (Krumholz 1954a, 1954b, 1954c). In the early studies, gross beta activity instead of the concentration of specific radionuclides was usually reported for the biota. In addition, the inherent variability in the parameters that were being measured in populations would preclude the effects of the radiation being detected at the dose rates the biota were receiving. From 1961 to 1977 a series of studies was carried out on the midge (*Chironomus tentans*) population (Blaylock 1965, 1966); the mosquitofish (*Gambusia affinis*) population (Blaylock 1969; Trabalka and Allen 1977); and the snail (*Physa heterostropha*) population (Cooley 1973) that inhabited WOL to determine the effects of irradiation on them. Blaylock and Trabalka (1978) concluded in an evaluation of these studies that it is highly unlikely that radiation effects on the populations of aquatic organisms in WOL would be detectable because of the decreasing dose rate being received by the organisms as a result of a decrease in the level of radioactivity in the lake over the years.

A more detailed review of the radioecology of WOL, including recent data on radionuclide and nonradiological contaminant concentrations in sediment and biota, is presented in Blaylock et al. (in preparation).

3.4.1.2 Bioaccumulation of Nonradiological Contaminants

The WOC, MB, WOL, and the WOC embayment water and sediments contain metals, organic chemicals, and radionuclides as a result of current and past discharges from ORNL (Boyle et al. 1982; Blaylock et al. in preparation). Fish collected from WOL and the WOC embayment in 1979 (Loar et al. 1981) and 1984 (TVA 1985) contained elevated levels of mercury, but the levels in 1984 were well below the 1 ppm (Facility Disposal Area (FDA) action limit and were significantly lower than levels observed in 1979. A comprehensive water-quality survey conducted in 1979 documented a sharp increase in aqueous-phase mercury levels in WOC as it passed through the central ORNL complex, and a large decrease in aqueous-phase mercury in the water after it passed through WOL (Boyle et al. 1982). Levels of mercury in biota in WOC and MB above WOL have not been measured. Measurements of aqueous-phase mercury levels made in 1985 suggest that releases have decreased substantially since 1979-1980, but measurements on a single date are not adequate to demonstrate such a decrease.

The concentrations of other metals, particularly zinc, chromium, and copper, are slightly elevated above background levels in WOC and MB water and sediments (Blaylock et al. in preparation). Measurements of other trace metals in fish from WOL and the WOC embayment in 1979 (Loar et al. 1981) and 1984 (TVA 1985) indicated that metals other than mercury did not exceed background levels. No measurements have been made of trace metals in fish upstream of WOL.

Polychlorinated biphenyls (PCBs) appear to constitute the most significant bioaccumulation problem associated with ORNL. High levels of PCBs were observed in WOC sediments in 1979 (Boyle et al. 1982), and levels in excess of the FDA action limit were found in all channel catfish collected in 1984 from the WOC embayment (TVA 1985). In the latter study, however, high levels of PCBs were not found in carp from WOL. Monitoring of PCBs in fish (carp, bluegill, largemouth bass, and shad) from the Clinch River at the mouth of WOC indicated levels above background, but most fish had PCB concentrations well below the FDA limit (Martin Marietta Energy Systems, Inc. 1985). One of four sediment cores taken in the WOC embayment in 1984 was high in PCBs, while the others were below detection limits. The data suggest that a "hot spot" of PCB-contaminated sediments occurs somewhere in the WOC embayment, which acts as a source of PCB contamination to bottom-dwelling fishes, such as channel catfish (Blaylock et al. in preparation). Reconstruction of the WOD spillway, completed in 1983, may have released buried PCB-contaminated sediments from WOL, which then accumulated in depositional areas in the WOC embayment. No significant accumulation of other organic compounds was observed in fish from WOL or the WOC embayment in 1984 (TVA 1985). Chloroform was reported in two catfish from the WOC embayment, but the low bioaccumulation potential of this compound (Callahan et al. 1979) makes its actual presence in fish highly unlikely. One sediment core from the WOC embayment contained 1.6 ppm bis(2-ethylhexyl) phthalate. This substance has a moderate bioaccumulation potential (Callahan et al. 1979) but poses a relatively low risk to consumers (Hoffman et al. 1984).

3.4.1.3 Surveys of aquatic biota, 1950 - 1980

The aquatic biota of the White Oak Creek watershed, including WOL, were first characterized more than 30 years ago by Krumholz (1954a, 1954b, 1954c). This initial survey described the composition and abundance of the plankton, benthic macroinvertebrate, and fish communities, and was followed by several other studies of a more limited scope. The protozoan and phytoplankton communities in WOL were investigated during the summer of 1956 (Lackey 1957). The composition of the fish community in the lake has been described by Kolehmainen and Nelson (1969) and Auerbach (1974); the nonradiological data collected in all three studies consisted primarily of species lists. Rather limited (but quantitative) sampling of the phytoplankton and zooplankton communities in WOL was conducted in 1972-1973 (A. S. Bradshaw, unpublished data), and the benthic macroinvertebrate communities were sampled at six sites in the WOC watershed in 1974-1975 (B. G. Blaylock, unpublished data).

The first comprehensive ecological survey of the watershed since 1953 was conducted from March 1979 through June 1980 to characterize the biological communities at selected sites on WOC above and below ORNL and on the Clinch River upstream and downstream from the confluence of WOC (Loar et al. 1981). The periphyton, benthic invertebrate, and fish communities were sampled at four sites in the

WOC watershed above WOL; these communities and three others (phytoplankton, zooplankton, and ichthyoplankton) were sampled in WOL, the WOC embayment, and the Clinch River (Fig. 8). The base-line information obtained by Loar et al. (1981), which was subsequently used to assess the nonradiological environmental impacts resulting from ORNL operations (Boyle et al. 1982), indicated degradation of the aquatic environment in WOC below ORNL. Of particular significance were the absence of fishes and the low diversity of benthic invertebrates at several sites. Potential causes of these impacts are (1) individual pollutants present at toxic levels, (2) multiple pollutants, acting synergistically, and (3) toxicants that have accumulated over the years in the sediments of WOC (Boyle et al. 1982).

In summary, most of the previous studies of the aquatic ecology of the WOC watershed evaluated the radioecological effects of ORNL discharges and were not designed to characterize the aquatic biota (i.e., the composition, abundance, and distribution of biotic communities). Only the 1950-1953 and 1979-1980 surveys conducted by Krumholz (1954a, 1954b, 1954c) and Loar et al. (1981), respectively, provided detailed descriptions of the aquatic communities of WOC and WOL. A more detailed review of the nonradiological studies on aquatic ecology of the watershed is presented in Loar et al. (1981).

3.4.1.4 Synoptic Survey, Summer 1985

A synoptic survey was conducted in August and September 1985 to (1) update results obtained in the comprehensive 1979-1980 survey and (2) assist in identifying sampling sites to include in the Biological Monitoring Plan and Abatement Program, as required by the NPDES permit for ORNL. This preliminary characterization included both instream sampling of biota (benthic invertebrates and fish) and ambient toxicity testing at 12-15 sites in the WOC watershed above WOL. All sampling, laboratory analyses, and data interpretation were conducted by staff in the Environmental Sciences Division at ORNL.

ORNL-DWG 80-15923R3

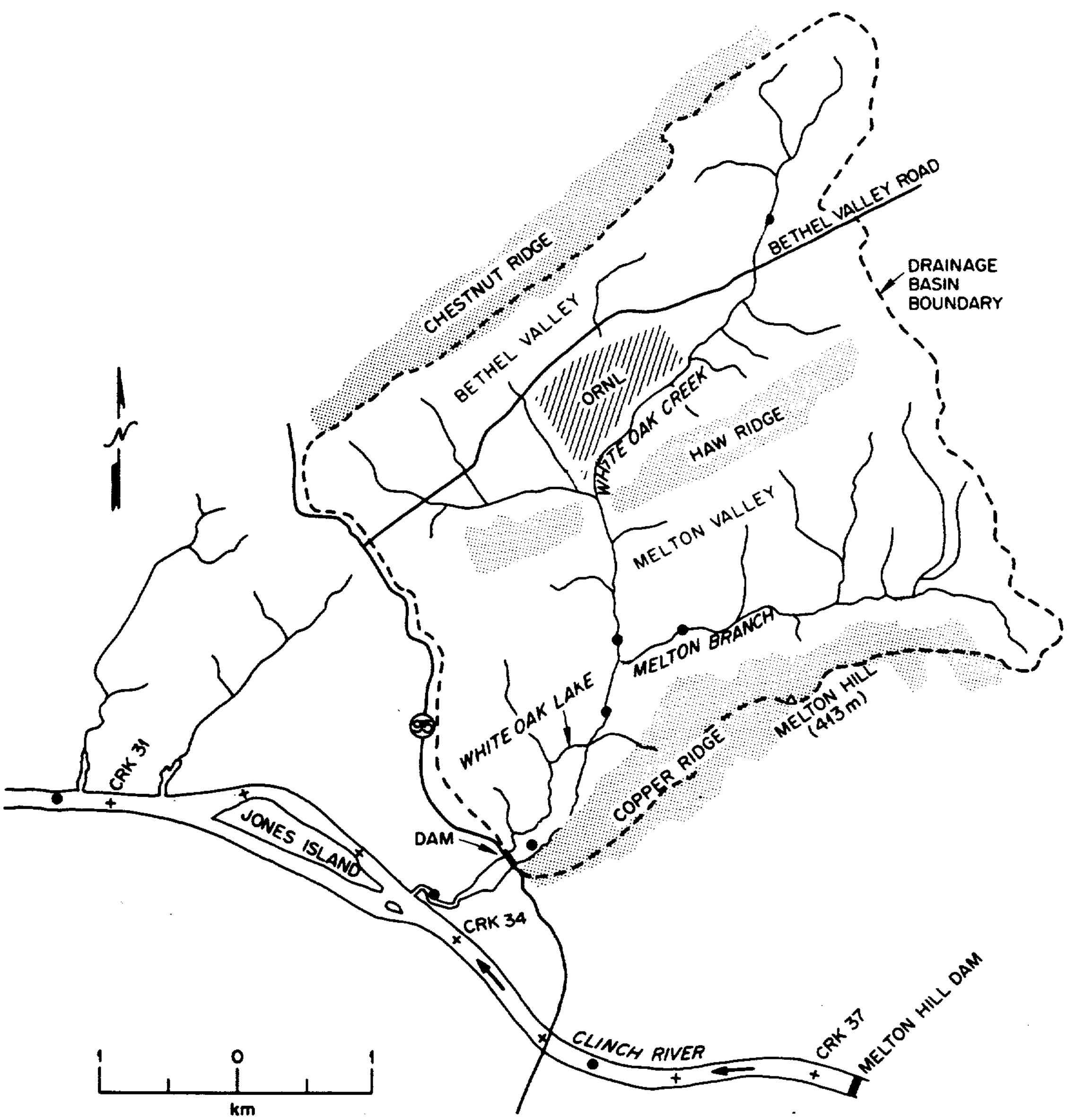

Fig. 8. Location of the eight sampling sites included in a 1979–1980 survey of aquatic biota in the vicinity of ORNL. Source: Loar et al. (1981).

Benthic invertebrate survey

Triplicate bottom samples were collected with a 0.09-m^2 Surber sampler on August 19-20, 1985, from designated riffle areas at each of 12 sites located on WOC (6 sites), on several tributaries, including MB (3 sites), Northwest Tributary, First Creek, and Fifth Creek (Fig. 9). In the laboratory, benthic organisms were separated from debris in white enamel pans and identified by genus, wherever possible. From these results, numerical abundance and the Shannon-Weiner diversity index were computed.

As observed in previous studies of the benthos in WOC (Krumholz 1954b; Blaylock, unpublished data, as reported in Loar et al. 1981; Loar et al. 1981), species richness (as represented by the mean number of taxa per sample and the total number of taxa per site) and species diversity were highest at the reference site [White Oak Creek Kilometer (WOCK) 6.8] located above ORNL and north of Bethel Valley Road (Table 6). Although the benthic fauna was numerically dominated by dipterans (32%) and the snail, _Goniobasis_ (23%), the insect orders Plecoptera (stoneflies), Ephemeroptera (mayflies), and Tricoptera (caddisflies) were well represented (Table 7), comprising 16%, 8%, and 3% of the total numbers, respectively.

Compared with the undisturbed community at WOCK 6.8, both density and species richness were substantially lower at all sites on WOC south of Bethel Valley Road. Species diversity (H') was also considerably lower at these sites than at WOCK 6.8, with the exception of WOCK 3.4 where the relatively high diversity can be attributed to the even distribution of individuals among the few species present. Further evidence of a significant impact on the benthic communities downstream of WOCK 6.8 is the substantial reduction in most major taxa; in many cases, major taxa were totally absent. Particularly striking was the total absence of stoneflies, snails (_Goniobasis_), most mayfly and caddisfly taxa, and several dipterans (e.g., _Zavrelia_) from WOCK 5.1 (Table 7); the dominant taxa at this site were the elmid beetle _Optioservus_ (35%) and chironomids (34%).

ORNL-DWG 79-14476R2

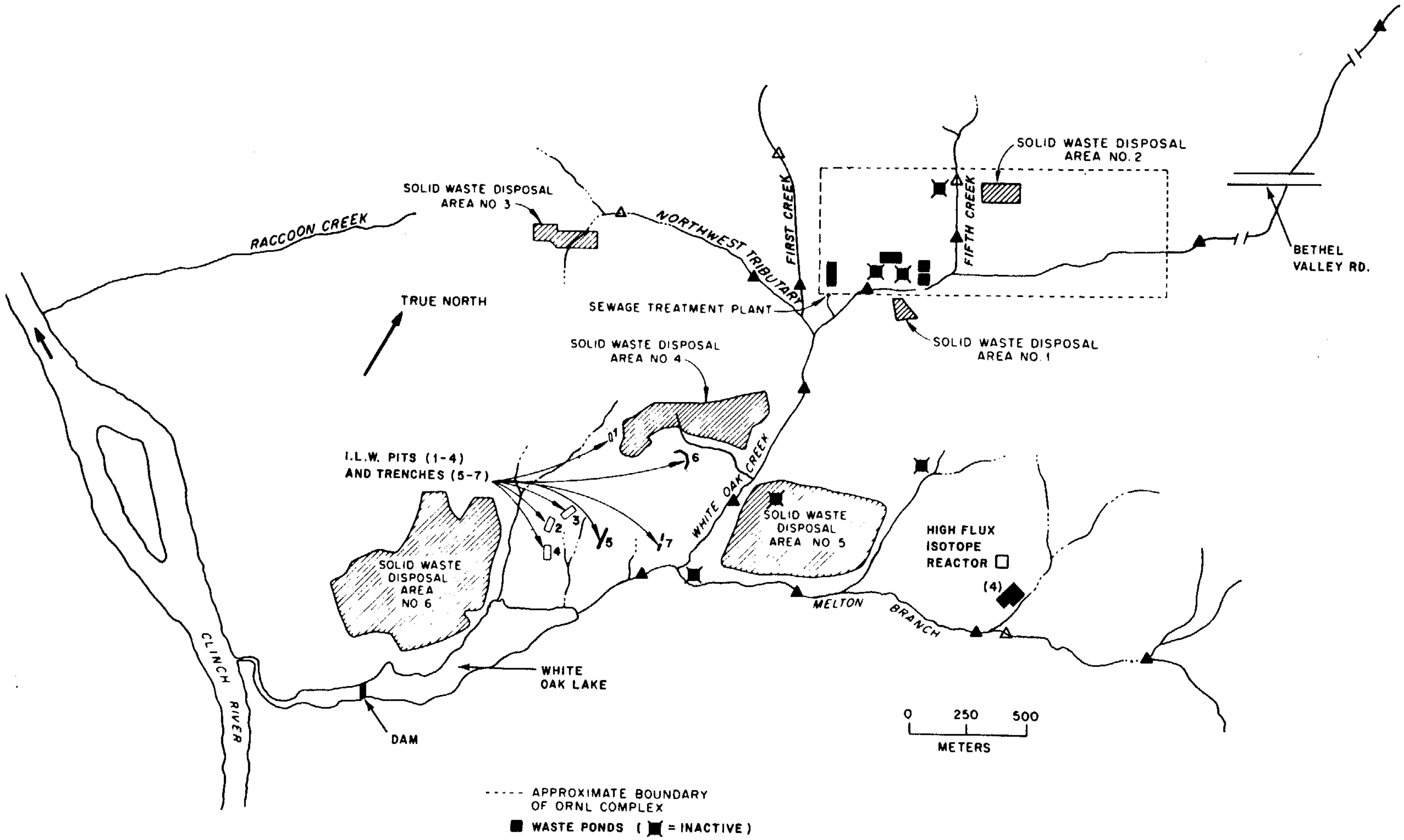

Fig. 9. Location of the 12 sites included in the synoptic benthic and fish surveys conducted in August-September 1985.

Table 6. Mean density (standard error), mean number of taxa (range), total number of taxa per site, and mean diversity (standard error) of benthic invertebrates in the White Oak Creek watershed, August 19-20, 1985[a]

Sampling site[b]	Mean density (no./0.1 m^2)	Mean number of taxa per sample (range)	Number of taxa per site	Mean species diversity (H')
FCK 0.1	354.5 (78.7)	13.7 (12-15)	23	0.53 (0.03)
FFK 0.2	17.2 (3.7)	9.7 (8-13)	22	0.92 (0.06)
MEK 0.6	27.3 (9.3)	10.6 (8-13)	19	0.90 (0.10)
MEK 1.4	37.0 (12.8)	15.7 (9-25)	31	1.06 (0.12)
MEK 2.1	141.7 (56.8)	24.7 (23-27)	45	1.11 (0.06)
NTK 0.3	65.3 (24.6)	14.0 (8-24)	28	0.75 (0.10)
WCK 2.3	79.7 (14.0)	8.7 (6-11)	17	0.49 (0.13)
WCK 2.9	31.2 (15.2)	8.3 (5-12)	17	0.70 (0.07)
WCK 3.4	66.7 (30.6)	14.7 (9-19)	26	0.92 (0.06)
WCK 3.9	14.0 (4.35)	8.3 (3-11)	17	0.79 (0.19)
WCK 5.1	89.3 (13.7)	14.0 (11-19)	25	0.75 (0.09)
WCK 6.8	448.5 (129.4)	36 (31-43)	56	1.08 (0.08)

[a]Values are based on three Surber samples taken at random from riffle areas at each site.

[b]FCK 0.1 = First Creek Kilometer 0.1 or 0.1 km above major confluence; FFK = Fifth Creek; MEK = Melton Branch; NTK = Northwest Tributary; WCK = White Oak Creek.

Table 7. Mean density (number per 0.1 m^2) of benthic invertebrates collected from White Oak Creek and tributaries, August 19-20, 1985

Taxon	Site[a]											
	FCK 0.1	FFK 0.2	MEK 0.6	MEK 1.4	MEK 2.1	NTK 0.3	WCK 2.3	WCK 2.9	WCK 3.4	WCK 3.9	WCK 5.1	WCK 6.8
Tricladida	0.4	—	—	2.2	—	—	—	—	—	—	—	—
Nematoda	1.4	—	0.7	—	0.4	—	—	0.4	0.4	—	1.1	0.7
Oligochaeta												
Lumbriculidae	13.3	—	0.7	0.4	1.8	—	—	—	1.1	—	—	3.2
Naididae	—	—	—	—	—	—	—	—	—	—	0.4	1.8
Tubificidae	39.5	1.4	2.5	—	18.3	2.2	1.1	1.1	0.7	2.2	3.2	20.5
Cladocera	—	—	—	—	—	0.4	—	—	—	—	—	—
Copepoda	—	—	—	—	0.4	—	—	1.1	—	—	0.4	—
Ostracoda	—	—	—	—	0.4	—	—	—	—	0.7	—	—
Isopoda												
Asellus sp.	—	0.4	—	—	—	—	—	—	—	—	3.6	—
Lirceus sp.	—	1.4	—	2.5	3.2	2.2	—	—	—		—	—
Amphipoda												
Crangonyx sp.	1.1	—	—	—	0.4	0.7	—	—	—		—	0.4
Decapoda												
Cambarus sp.	—	—	—	—	—	0.7	—	—	—	—	—	2.2
Hydracarina	—	—	—	—	—	—	—	—	—	—	—	0.4
Ephemeroptera												
Baetis spp.	0.4	—	1.1	4.7	1.8	—	—	—	0.4	0.4	0.4	6.1
Ephemera sp.	—	—	—	2.2	—	—	—	—	—	—	—	0.4
Habrophlebiodes sp.	—	—	—	—	0.4	—	—	—	—	—	—	0.7
Isonychia sp.	—	—	—	—	—	—	—	—	—	—	—	27.6
Stenonema sp.	—	—	—	2.9	1.4	0.7	—	—	—	—	—	3.5
Heptageniidae	—	—	—	—	—	—	—	0.4	—	—	—	—
Leptophlebiidae	—	0.4	—	—	—	—	—	—	—	—	—	—
Odonata												
Argia sp.	—	—	0.4	—	—	—	—	—	—			—
Coenagrionidae	—	—	—	—	—	—	0.4	0.4	0.7	—	0.4	—
Stylogomphus sp.	—	—	—	—	—	1.8	—	—	—	—	—	3.6
Stylogomphus ? sp.	—	—	—	1.1	0.7	—	—	—	—	—	—	0.4
Gomphidae	—	—	—	—	1.4	—	—	—	—	—	—	—

Table 7 (continued)

Taxon	Site[a]											
	FCK 0.1	FFK 0.2	MEK 0.6	MEK 1.4	MEK 2.1	NTK 0.3	WCK 2.3	WCK 2.9	WCK 3.4	WCK 3.9	WCK 5.1	WCK 6.8
Plecoptera												
<u>Leuctra</u> sp.	--	--	--	--	--	--	--	--	--	0.4	--	66.7
Chloroperlidae	--	--	--	0.4	--	--	--	--	--	--	--	6.1
Perlidae	--	--	--	--	--	--	--	--	--	--	--	0.4
Unidentified	--	--	--	--	0.4	--	--	--	--	--	--	--
Hemiptera												
Corixidae	--	--	--	--	--	--	--	--	0.7	--	--	--
Megaloptera												
<u>Nigronia</u> sp.	--	--	--	0.4	4.3	--	--	--	1.4	0.4	--	2.9
<u>Sialis</u> sp.	--	--	--	--	2.2	0.4	--	--	--	--	--	10.0
Tricoptera												
<u>Chimarra</u> sp.	--	--	1.1	0.4	--	--	--	--	--	0.4	--	--
<u>Wormaldia</u> sp.	--	--	--	--	--	--	--	--	0.4	--	--	1.8
<u>Lype</u> sp.	--	--	--	--	--	0.4	--	--	--	--	--	1.1
<u>Polycentropus</u> sp.	--	--	--	--	--	--	--	--	--	--	--	0.7
<u>Cheumatopsyche</u> sp.	5.4	0.4	5.4	--	--	24.0	17.2	4.7	4.7	--	2.2	2.5
<u>Diplectrona modesta</u>	--	--	--	--	0.4	--	--	--	--	--	--	5.0
<u>Hydropsyche</u> sp.	--	--	--	--	--	--	5.4	0.7	--	--	--	0.4
<u>Lepidostoma</u> sp.	--	--	--	--	--	--	--	--	--	--	--	0.4
<u>Neophylax</u> sp.	--	--	--	--	--	0.4	--	--	--	--	--	--
<u>Goera</u> sp.	--	--	--	--	--	--	--	--	--	--	--	1.1
<u>Psilotreta</u> sp.	--	--	--	--	--	--	--	--	--	--	--	1.1
Coleoptera												
<u>Berosus</u> sp.	--	--	--	--	--	--	--	--	--	0.4	--	--
<u>Cymbiodyta</u> sp.	--	--	--	--	--	--	--	--	--	--	--	0.4
<u>Helophorus</u> sp.	--	--	--	--	0.4	--	--	--	--			--
<u>Laccobius</u>	--	--	--	--	--	--	--	--	--	--	--	0.4
Hydrophilidae	--	--	--	--	0.4	--	--	--	--	--	--	--
<u>Psephenus herricki</u>	0.7	--	--	--	--	--	--	0.4	1.4	--	--	5.0
<u>Ectopria</u> sp.	0.4	--	1.4	--	6.1	--	--	--	--	0.4	9.0	--
<u>Dryops</u> sp.	--	--	--	--	--	--	0.4	--	--	--	--	--
Dryopidae	--	--	--	--	--	--	0.4	--	--	--	--	--

Table 7 (continued)

Taxon	Site[a] FCK 0.1	FFK 0.2	MEK 0.6	MEK 1.4	MEK 2.1	NTK 0.3	WCK 2.3	WCK 2.9	WCK 3.4	WCK 3.9	WCK 5.1	WCK 6.8
Ancycronyx sp.	--	--	--	0.4	--	--	--	--	--	--	--	--
Optioservus sp.	66.0	3.2	1.1	3.6	24.0	19.4	1.1	1.4	3.9	--	30.9	17.2
Stenelmis sp.	206.3	1.8	7.2	5.0	36.2	3.9	49.2	15.4	16.9	--	0.4	0.7
Anchytarsus bicolor	--	--	--	--	--	--	--	--	--	--	--	8.3
Unidentified sp. A	--	--	--	--	--	--	--	--	0.4	--	--	--
Unidentified sp. B	--	--	--	--	--	--	--	0.4	--	--	--	--
Unidentified sp. C	--	--	--	--	--	--	--	0.4	--	--	--	--
Diptera												
Tipula sp.	--	--	--	--	--	--	--	--	--	0.4	0.4	0.4
Antocha sp.	--	0.4	--	--	--	--	--	--	--	--	--	1.8
Dactylolabis sp.	--	--	--	--	--	0.4	--	--	0.4	--	--	--
Limonia sp.	--	--	--	0.4	0.4	--	--	--	--	--	--	--
Pseudolimnophila sp.	--	--	--	--	--	0.7	--	--	--	--	--	0.4
Tipulidae												
Unidentified sp. A	--	--	--	--	--	--	--	--	--	--	0.4	--
Unidentified sp. B	--	--	--	--	0.4	--	--	--	--	--	--	--
Tipulidae ?	--	0.4	--	--	--	--	--	--	--	--	--	--
Dixa sp.	--	--	0.4	--	--	--	--	--	--	--	--	1.1
Atrichopogon sp.	--	--	--	--	0.4	--	--	--	0.4	--	--	--
Bezzia/Palpomyia	--	--	--	--	1.1	--	--	--	--	--	--	--
Palpomyia/Sphaeromia	--	--	--	--	0.7	--	--	--	--	--	--	--
Larsia ? sp.	--	--	--	0.4	--	--	--	--	--	--	--	--
Nilotanypus sp.	--	--	--	--	--	--	--	--	--	--	--	0.7
Paramerina sp.	--	--	--	--	0.7	--	--	--	--	--	--	0.4
Psectrotanypus sp.	--	--	--	--	--	--	--	--	0.4	--	--	--
Thienemannimyia complex	1.1	0.4	0.7	1.1	2.2	0.7	1.1	--	1.8	--	0.7	7.2
Tanypodinae												
Unidentified	--	--	0.4	--	--	--	--	--	--	--	--	--
Cardiocladius sp.	0.4	0.4	--	--	--	--	1.1	--	15.1	--	--	0.4
Corynoneura sp.	--	--	--	--	0.7	--	0.4	--	0.4	--	--	--
Cricotopus sp.	--	0.4	--	--	--	--	--	--	--	--	--	--
Cricotopus/Orthocladius	11.5	0.4	1.8	0.4	--	--	0.4	0.4	8.3	3.6	24.4	--
Eukiefferiella sp.	--	--	--	--	0.4	--	--	--	--	--	--	3.6
Parametriocnemus sp.	--	--	--	1.4	11.5	0.4	--	--	--	--	--	3.6

Table 7 (continued)

Taxon	Site[a] FCK 0.1	FFK 0.2	MEK 0.6	MEK 1.4	MEK 2.1	NTK 0.3	WCK 2.3	WCK 2.9	WCK 3.4	WCK 3.9	WCK 5.1	WCK 6.8
Psectrocladius sp.	--	--	--	0.7	--	--	--	--	--	--	--	--
Rheocricotopus sp.	--	--	--	0.4	--	--	--	--	--	--	--	--
Smittia sp.	--	--	--	--	--	--	--	--	--	--	--	0.4
Chironomus sp.	--	0.7	--	--	--	--	--	0.4	2.9	0.4	--	--
Cryptochironomus sp.	0.4	--	--	0.4	--	--	--	--	--	--	--	--
Dicrotendipes sp.	--	--	--	--	0.4	--	--	--	--	--	1.4	--
Microtendipes sp.	--	--	--	0.4	1.4	0.4	--	--	--	--	--	--
Paratendipes sp.	--	0.4	--	0.4	0.4	0.4	--	--	0.4	0.4	--	--
Phaenopsectra sp.	--	--	--	0.4	--	0.4	--	--	--	--	--	--
Polypedilum sp.	--	0.4	1.1	1.4	1.1	--	0.4	--	--	--	2.2	1.4
Stenochironomus sp.	0.4	--	0.4	--	--	--	--	--	--	--	--	--
Micropsectra sp.	--	--	--	1.4	2.9	--	--	--	--	--	--	22.2
Rheotanytarsus sp.	0.4	--	--	--	0.7	0.7	--	--	--	1.1	--	16.9
Tanytarsus sp.	0.4	0.7	--	0.7	1.1	0.7	--	--	--	0.4	0.7	--
Zavrelia sp.	--	--	--	1.8	2.9	0.4	--	--	--	1.4	--	75.7
Chironomidae	1.4	0.7	0.4	--	1.4	--	--	--	--	--	0.7	2.9
Simulium sp.	--	--	--	--	--	0.4	--	--	--	--	--	2.5
Chrysops sp.	--	0.4	--	--	--	--	0.5	2.2	1.1	--	0.4	--
Tabanus sp.	--	--	--	--	--	--	--	--	--	0.7	--	0.7
Tabanidae	--	--	0.4	--	--	--	--	--	--	--	--	--
Oxycera	--	--	--	--	--	--	--	--	--	--	0.4	--
Stratiomys sp.	--	--	--	--	--	--	0.4	--	--	--	--	--
Empididae	1.8	1.4	--	0.4	--	--	0.4	1.4	2.2	0.7	--	--
Dolichopodidae	--	--	--	--	0.4	--	--	--	--	--	--	--
Notiphilinae	--	--	--	--	--	--	--	--	0.4	--	--	--
Diptera	0.4	--	--	--	--	--	--	0.4	--	--	--	--

Table 7 (continued)

Taxon	Site[a] FCK 0.1	FFK 0.2	MEK 0.6	MEK 1.4	MEK 2.1	NTK 0.3	WCK 2.3	WCK 2.9	WCK 3.4	WCK 3.9	WCK 5.1	WCK 6.8
Gastropoda												
Goniobasis sp.	--	--	--	--	--	--	0.4	--	--	--	--	101.5
Laevipex sp.	--	--	--	--	2.5	--	--	--	--	--	0.4	--
Ancylidae	--	--	--	0.4	0.7	0.4	--	--	--	--	--	--
Lymnaea sp.	0.4	--	--	0.4	0.7	--	--	--	--	--	--	--
Valvata sp.	--	0.4	--	--	--	--	--	--	--	--	--	--
Hydrobiidae	--	--	--	--	--	0.7	--	--	--	--	--	--
Unidentified sp. A	--	0.4	--	--	--	--	--	--	--	--	--	--
Unidentified sp. B	--	1.1	--	--	--	--	--	--	--	--	--	--
Unidentified sp. C	--	--	--	--	--	--	--	--	--	--	0.4	0.4
Unidentified sp. D	--	--	--	--	--	--	--	--	--	--	--	0.4
Unidentified sp. E	--	--	--	--	0.4	--	--	--	--	--	--	--
Pelecypoda												
Pisidium sp.	--	--	--	--	--	--	--	--	0.4	--	--	--
Sphaeriidae	--	--	--	--	--	--	--	--	0.4	--	--	--

[a]See Table 6, footnote 'b', for identification of sampling sites.

Unlike previous studies in which chironomids were found to be the dominant group in WOC below ORNL (Krumholz 1954b and Blaylock, unpublished data, as reported in Loar et al. 1981; Loar et al. 1981), the dominant taxon found in the present survey was the elmid beetle (Stenelmis); only at WOCK 3.4 were chironomids the dominant group (44%). A considerable increase in hydropsychid caddisflies at the downstream site (WOCK 2.3) was observed in the 1985 survey. The only other study reporting the occurrence of caddisflies below ORNL was the 1979-1980 survey of Loar et al. (1981), in which the hydropsychid (Cheumatopsyche), was found at WOCK 2.7 in very low densities (4 individuals/m^2; J. M. Loar, unpublished data). The large increase in hydropsychids since 1980 could be the result of an increase in their food supply and/or an improvement in water quality. For example, construction of new weirs and/or modification of existing weirs on WOC and MB may have enhanced primary production in the small impoundments just above the weirs and provided a food source for downstream filter-feeding species like Cheumatopsyche.

Results of the 1985 survey indicate that a highly diverse benthic fauna inhabits MB above the tributary that receives discharges from HFIR (Fig. 9), whereas the two sites below HFIR were adversely impacted (Table 6). Similar results were obtained by Blaylock (unpublished data, as reported in Loar et al. 1981) in a 1974-1975 survey. The high H' value at station Melton Branch Kilometer (MBK) 1.4, which was located only 30 m below the confluence with the HFIR tributary (Fig. 9), was due to a lack of dominance by any one taxon. The collection of a relatively large number of taxa at this site could be the result of invertebrate drift from unimpacted upstream areas. Density and species richness declined considerably at the lowest station on MB (MBK 0.6), but H' remained relatively high, due again to the lack of dominance by any one taxon. Five years ago, the fauna at MBK 0.6 was dominated by chironomids (80%) and elmid beetles (11%); mayfly densities were low and no caddisflies were found (Loar et al. 1981). Although mayfly densities remained low, caddisflies in the present survey comprised 24% of the total organisms collected at this site. These results suggest that a moderate shift in species composition has occurred since 1980, but an adverse impact on the benthic community in lower MB still exists.

The benthic invertebrate community of Northwest Tributary [Northwest Tributary Kilometer (NTK) 0.3] appears somewhat impacted (Table 6). The fauna at this site was dominated by elmid beetles (36%) and *Cheumatopsyche* (37%); chironomids constituted only 6% of the benthos (Table 7). A benthic community dominated by *Cheumatopsyche* (57%) and chironomids (25%), and to a lesser extent by elmid beetles (8%), was observed based on limited sampling conducted in 1974-1975 (B. G. Blaylock, unpublished data). Mayfly densities were relatively low and stoneflies were absent in both studies. Although sampling was limited in the earlier survey, the results of the two studies seem to indicate that no major change has occurred in the benthic community of Northwest Tributary between 1974 and 1985.

The low species richness and diversity observed in First Creek [First Creek Kilometer (FCK) 0.1] are indicative of environmental stress (Table 6). This site was dominated by elmid beetles (77%) and oligochaetes (15%) (Table 7). Although total density was very high, very low numbers of mayflies and caddisflies were collected, and stoneflies were absent.

Fifth Creek [Fifth Creek Kilometer (FFK) 0.2] was one of the most impacted sites included in the 1985 survey (Table 6). Density and species richness were low, and species diversity was high due to a lack of dominance by any taxa. The most abundant taxa included elmid beetles (29%) and chironomids (26%).

Fish survey

Fish sampling was conducted between August 14 and September 18, 1985, using one or two (depending upon the width of the stream) Smith-Root Model 15A backpack electrofishers. Sampling was conducted near the 12 sites included in the benthos survey and at additional control sites on upper Fifth Creek, First Creek, and MB (Fig. 9).

Densities of each species were calculated from population estimates based on the removal method (Carle and Strub 1978), with three consecutive passes at each site.

Fish densities in WOC ranged from less than 0.1 individuals/m^2 at station WOCK 3.9 near the main ORNL complex to 10.1 individuals/m^2 at WOCK 5.1 just east of ORNL (Table 8). Densities at the three sites below ORNL were low (less than 0.30 individuals/m^2) and, with the exception of station WOCK 2.3, species richness was also low. Whereas few species typically inhabit the small, undisturbed, headwater streams on the Department of Energy Oak Ridge Reservation, such as the upper reaches of MB, WOC, and First Creek (Table 8), species richness generally increases downstream, due, in part, to increased streamflow and greater habitat diversity. Consequently, the low abundance and number of species in lower WOC are indicative of an impacted community. The magnitude of the impacts in 1985, however, was less than that observed in a 1979-1980 survey in which no fish were found at stations MBK 0.6 and WOCK 2.7 (Loar et al. 1981). Finally, the very high density observed at station WOCK 5.1 is unusual and exceeds the densities typically found in streams of this size by a factor of 2 or 3 (e.g., MB, First Creek, and upper WOC, Table 8; Grassy Creek, Loar et al. 1985). Such high densities may reflect (1) transitory shifts in distribution resulting from adverse conditions not far downstream (Fig. 9) or (2) increase in food availability (periphyton production). For example, densities of the central stoneroller, a periphyton grazer, increased from 0.03 to 4.28 individuals/m^2 between sites WOCK 6.8 and WOCK 5.1, respectively.

Adverse impacts were also observed on the fish communities in several tributaries of WOC, especially Fifth Creek and lower MB. No fish were collected in Fifth Creek or in MB just below the confluence with a small tributary that receives effluents from HFIR, including blowdown from the cooling towers. Water temperatures at this latter site (MEK 1.4) exceeded 33°C on the day of sampling; similar results were obtained in May 1985 at a water temperature of 36°C (G. F. Cada, unpublished data).

Table 8. Fish densities (number of fish/m^2) in White Oak Creek and tributaries above White Oak Lake, August-September 1985

Species	Site[a]														
	FCK 0.1	FCK 0.5	FFK 0.2	FFK 0.4	MEK 0.6	MEK 1.4	MEK 1.5	MEK 2.1	NTK 0.3	WCK 2.3	WCK 2.9[b]	WCK 3.4	WCK 3.9[b]	WCK 5.1	WCK 6.8
Centrarchidae															
Bluegill	0.10	–	–	–	–	–		–	0.02	0.07	–	0.04	0.01	–	–
Largemouth bass	–	–		–	–	–		–	0.01	0.01	–				–
Redbreast sunfish	–	–		–	0.12	–	–		–	0.13	0.01	0.03			–
Rock bass	–	–			–	–			–	0.01	–	–	–	–	–
Warmouth	–	–	–	–	–	–	–		–	0.01	–	–		–	–
Cottidae															
Banded sculpin	–	0.02	–		–		–	–	–	–	–	–	–	–	0.52
Cyprinidae															
Blacknose dace	2.30	4.14	–	–	0.01	–	0.63	3.54	0.26	–	–		–	5.19	2.66
Central stoneroller	–	–	–	–	–	–	–	–	–	–	–		–	4.28	0.03
Creek chub	0.05	0.04	–	–	0.30	–	0.54	1.75	–		–		–	0.64	0.05
Fathead minnow	0.02	–	–	–	–	–		–	0.01	–	0.01	0.01	0.01	–	–
Ictaluridae															
Black bullhead	–	–	–	–	–	–	–	–	–	0.01	–	–	–	–	–
Poeciliidae															
Mosquitofish	0.04	–	–		–	–		–	0.37	0.06	0.03	0.13			–
Number of species	5	3	0	0	3	0	2	2	5	7	3	4	2	3	4
Total density	2.52	4.21	–	–	0.43	–	1.17	5.30	0.68	0.28	0.03	0.20	0.01	10.12	3.26
Length of stream sampled (m)	61	28	71	30	53	50	124	21	70	98	96	128	163	42	52

[a]See Table 6, footnote 'b', for identification of sampling sites.

[b]Based on one pass through the sampling section; densities are based on actual numbers of fish collected (total of 17 and 3 fish at WCK 2.9 and WCK 3.9, respectively).

The synoptic ecological characterization conducted in 1985 identified several areas in the WOC watershed that appear to be significantly impacted by current operations at ORNL. These areas are Fifth Creek, lower MB below HFIR, and WOC below ORNL, especially that reach of WOC adjacent to the ORNL complex. All three areas are close to blowdown discharges from cooling towers. The distribution of fish densities among sampling sites was, with few exceptions, similar to that of benthos densities (Fig. 10). In WOC below ORNL, for example, the initial increase in density at WCK 3.4, followed by a decrease at WCK 2.9 near SWSA 4, was observed in both the benthos and fish surveys. The two surveys also provided evidence that the impacts on First Creek and Northwest Tributary are moderate in comparison to the impacts on these other areas. The general similarity in the response of the benthic invertebrate and fish communities among the 12 sites suggests that either (1) the sources of impacts on the two communities are similar and each community responds independently of the other or (2) only the benthic community is directly impacted, but the impact is propagated via the food chain (e.g., reduced food availability) to the fish community. Additional studies are needed to identify the nature and source(s) of impact and its ecological effects and to develop appropriate mitigation or remedial actions (Sect. 4.4).

Ambient toxicity evaluation

Toxicity tests were conducted to characterize conditions in WOC and in selected tributaries with respect to the toxicity of the ambient water to aquatic life. Chemical analysis has traditionally been used to characterize ambient water quality in streams receiving effluents. However, toxicity testing is a useful supplement or even a preferred alternative to chemical analysis in many situations because (1) it is rapid and economical; (2) many chemical constituents of complex effluents are difficult to analyze; (3) some toxic constituents may be unsuspected and therefore not measured; (4) toxicological interactions among effluent constituents, and between those constituents and other components in the receiving water, are unpredictable; and (5) toxicity

ORNL-DWG 86-9269

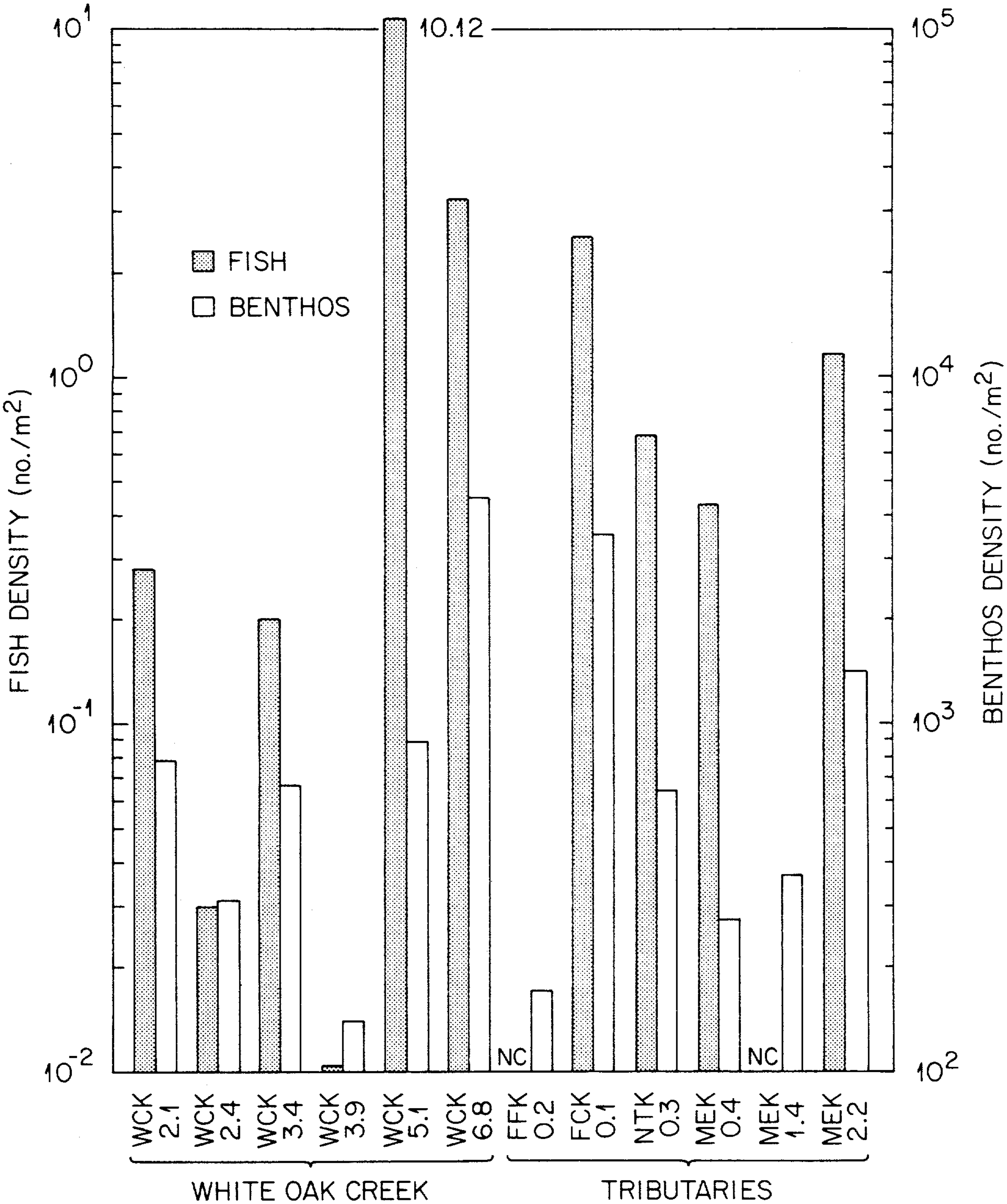

Fig. 10. Comparison of benthos and fish densities at 12 sites on White Oak Creek and selected tributaries.

testing gives a direct indication of potential hazards to aquatic life. Indeed, EPA policy was revised in 1984 to encourage the incorporation of toxicity testing in effluent regulation and permitting, instead of or in addition to chemical analyses.

Toxicity tests were conducted on August 6-13 and August 21-28, 1985, and on February 20-27, 1986, using "short-chronic" test methods recently developed by EPA and others specifically for effluent monitoring and ambient toxicity testing (Peltier and Weber 1985). One method measures effects of substances on the survival and growth of the fathead minnow (Pimephales promelas) during the first 7 d after hatching. The second method measures effects on survival and reproduction of a crustacean zooplanktes, Ceriodaphnia. These tests are the most sensitive short-term aquatic toxicity tests currently available.

In the initial test, water was collected from six sites on WOC from the headwaters north of Bethel Valley Road to a site above WOL (sites 1, 2, 4, 5, 6, and 7, as shown on Fig. 11), and from sites on First Creek (site 12), Fifth Creek (site 3), Northwest Tributary (site 11), and MB (sites 8, 9, and 10). Fathead minnow larvae were placed in water from each site, and the water was replaced daily (from the original sample). Fish exposed to water from Fifth Creek and from WOC just below the confluence with Fifth Creek (sites 3 and 4, respectively) suffered high mortality the first night of the test. Water from the 10 other sites did not appear to be toxic (i.e., survival exceeded 95%). Conductivity, hardness, alkalinity, and pH values for sites 3 and 4 did not differ markedly from those of the other 10 sites. The pattern of mortality over time suggested the presence of a volatile toxicant. Because of the presence of the Oak Ridge Research Reactor cooling tower on Fifth Creek, it was hypothesized that the cooling tower was releasing residual chlorine or bromine in toxic amounts. On August 9, 1985, a level of 0.40 mg/L total residual halogen was measured in Fifth Creek; previous studies have shown this level to be above the lethal level for fish (see review by Mattice and Zittel 1976).

ORNL-DWG 80-15923R

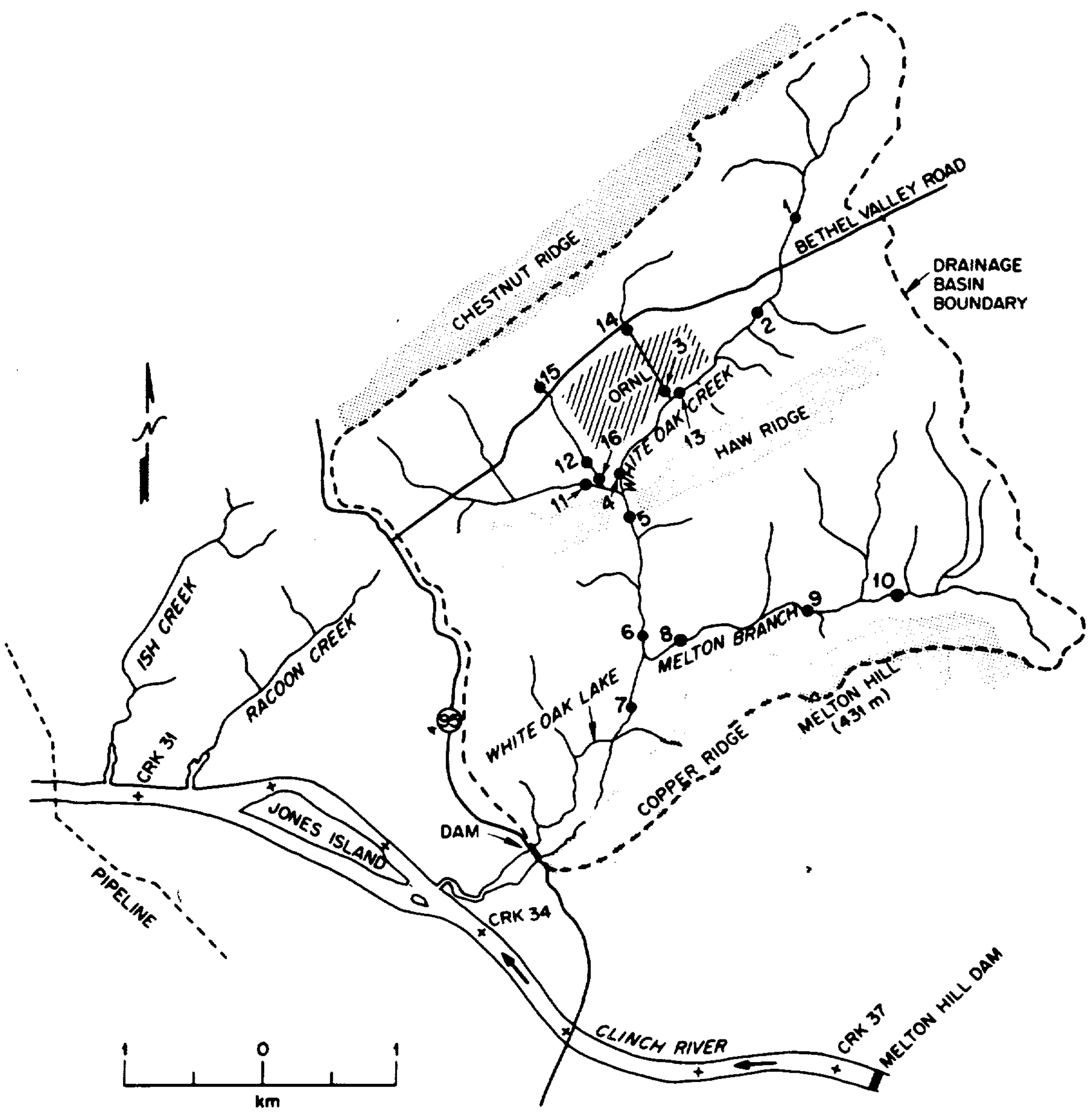

Fig. 11. Map showing 16 sites from which water was collected for toxicity tests.

In the August 21-28, 1985, experiments, water from sites 1, 3, 4, 5, and 6 (and from two new sites: sites 13 and 14, Fig. 11) was tested with fathead minnow larvae; water from sites 3 and 4 was also tested with Ceriodaphnia. Water from site 3 caused 10% mortality of fathead minnow larvae on two of the 7 d of the test (August 23 and 28, 1985), and fathead minnow larvae suffered complete mortality from water collected from site 13 on August 25-28, 1985. The water from the five other sites tested in this experiment (sites 1, 4, 5, 6, and 14) was nontoxic to fathead minnow larvae. Survival of Ceriodaphnia was 11% in water from site 13 and 0% in water from site 3 after 3 d. Interpretation of data from the Ceriodaphnia test was confounded by the fact that survival of Ceriodaphnia in control water was only 80%. Daily chemical analyses of the water collected for these experiments showed that alkalinity values ranged from 60 to 140 mg/L as $CaCO_3$; hardness values, from 82 to 164 mg/L as $CaCO_3$; pH values, from 7.19 to 8.03; and conductivity, from 104 to 600 µmho/cm. Chlorine was implicated as a possible intermittent contributor to toxicity in water from sites 3 and 13: over the 7-d test period, daily concentrations (mean $\pm$ standard deviation) of total residual chlorine for control water and for water from sites 3 and 13 averaged 0.047 $\pm$ 0.014, 0.101 $\pm$ 0.071, and 0.077 $\pm$ 0.063 ppm, respectively.

Measurements of free and total chlorine in water from 12 sites on WOC, and from 11 sites in tributaries to this stream were also made on September 9, 12, and 16, 1985. The results of these measurements showed that WOC sites downstream from site WOC 2 (Fig. 12) had higher total chlorine concentrations (0.178 $\pm$ 0.169, mean $\pm$ standard deviation, n = 23 across all dates) than more upstream sites (undetectable at four sites on all three dates). Water from five sites in lower Fifth Creek (sites T1, T1B, T1C, T1D, and T1E; Fig. 12) also contained elevated levels of total chlorine (0.200 $\pm$ 0.122 ppm, mean $\pm$ standard deviation, n = 15 across all dates) compared to two sites farther upstream (0.005 $\pm$ 0.005 ppm, mean $\pm$ standard deviation, n = 6 across all dates). The total chlorine in Northwest Tributary (NWT; Fig. 12)

ORNL-DWG 86-9270

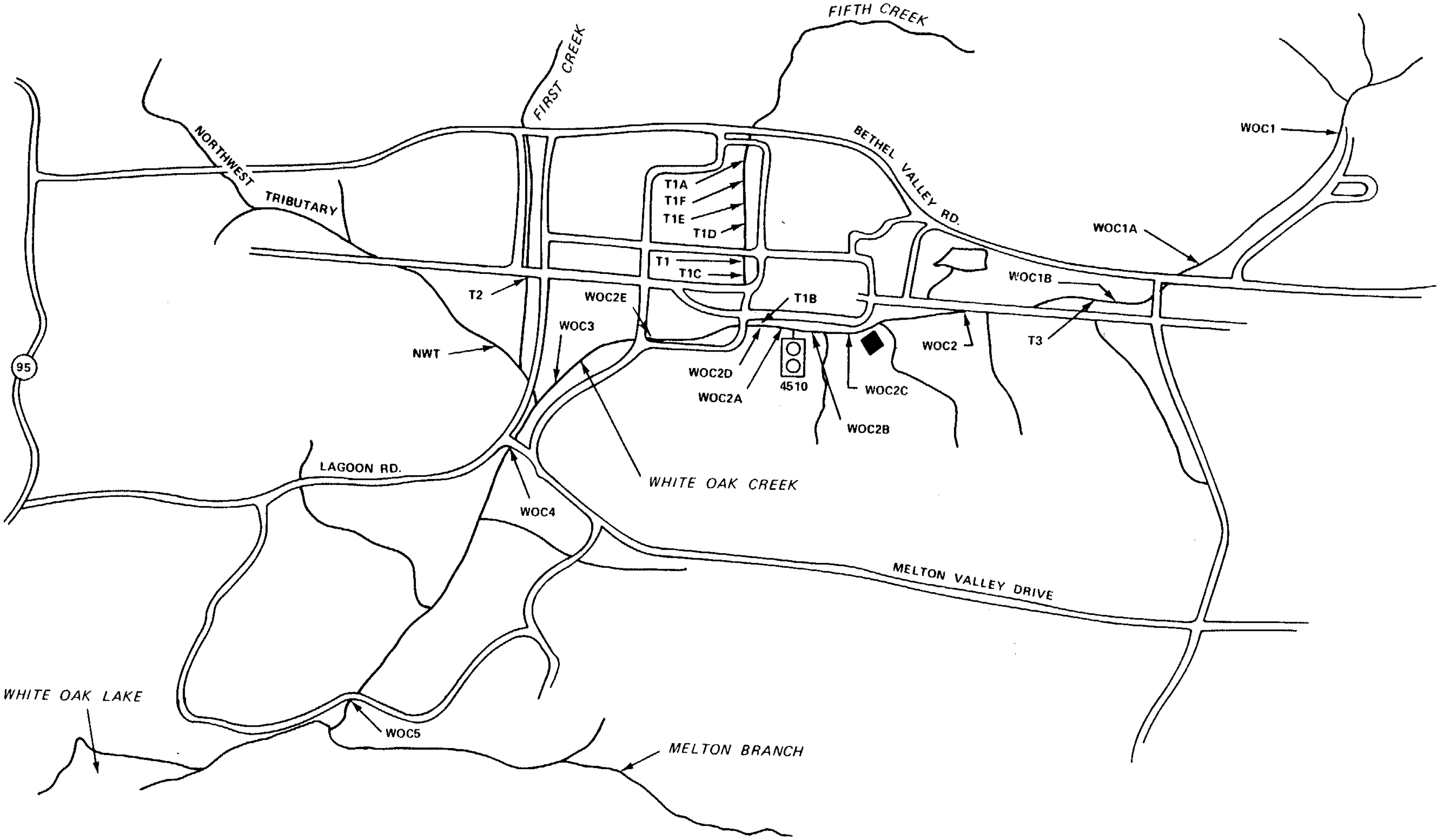

Fig. 12. Map showing location of White Oak Creek, Fifth Creek, First Creek, and Northwest Tributary sites from which water was taken for measurements of chlorine.

water on September 12 and 16 was undetectable, whereas total chlorine in lower First Creek (site T2) averaged 0.13 ppm (± 0.01 standard deviation for the three dates).

Daily grab samples of water from sites 15 and 16 (Fig. 11) were tested with Ceriodaphnia on February 20-27, 1986. Although this test was flawed by the erratic mortality and low fecundity of the animals in the controls, results suggested that water from this tributary to WOC was not toxic. The mean number of offspring per female raised in control water and in water from upper and lower First Creek sites were 10.7 ± 8.1, 8.3 ± 6.4, and 8.9 ± 4.7 (mean ± standard deviation), respectively. Summary statistics for daily measurements of pH, conductivity, alkalinity and hardness during this test are shown in Table 9.

Based on the results of these tests, it was concluded that water in lower Fifth Creek and at some sites on WOC (1) is toxic to minnow larvae and Ceriodaphnia and (2) contains relatively high levels of residual halogen (more than 0.1 mg/L) at some times and places. Results of these toxicity tests were confirmed by the instream surveys, which revealed very low benthos densities and very few or no fish near the same sites (Fig. 10). Further, cooling tower blowdown is responsible for some, but not all, of the residual halogen detected in Fifth Creek and WOC. The correlation between the measured total residual halogen in the water and the measured toxicity of the water to the test organisms was not exact, suggesting that other toxicants may also be present in the water.

3.4.2 Terrestrial Ecology

3.4.2.1 Radioecology

The principal areas where terrestrial radioecological studies have been conducted in the watershed include (1) the WOL bed, (2) seepage areas east and west of LLW seepage pits 2, 3, and 4, (3) the cobalt seep area east of trench 7, and (4) the WOC floodplain south of SWSA 4 (Fig. 2). Previous studies conducted in the WOL bed showed that soils in the upper lake bed exhibited significantly elevated concentrations

Table 9. Mean values for chemical parameters measured in upstream (just north of Bethel Valley Road) and downstream (just upstream from the confluence of First Creek with Northwest Tributary) sites of First Creek, February 20-27, 1986

(Sampling sites correspond to sites 15 and 16 in Fig. 12. Numbers in parentheses show coefficient of variation associated with day-by-day differences)

Sampling site	pH	Conductivity[a]	Alkalinity[b]	Hardness[c]
Upper First Creek	7.84 (2.3)	138 (12.7)	81.7 (13.4)	96.4 (10.9)
Lower First Creek	8.00 (1.5)	202 (16.3)	105.5 (17.2)	123.0 (8.7)

[a] umho/cm, corrected to 20°C.
[b] mg/L as $CaCO_3$, titrated to an endpoint of pH = 4.50.
[c] mg/L as $CaCO_3$.

of ^{137}Cs, ^{60}Co, ^{106}Ru, stable calcium, sodium, and phosphorus (Auerbach 1959). Effluents carrying radionuclides entered the upper lake bed from the east seep area, which drained a portion of the LLW seepage pit area. Strontium-90, also present in elevated concentrations, showed considerable decline in the lower lake bed soils (approximately 50% loss from soil in 1.25 years) from 1956 to 1958; however, upper lake bed soils were losing ^{90}Sr at a slower rate. The estimated ^{90}Sr inventory in soil for the 16.2-ha (40 acre), vegetated portion of the lake was 11.7 Ci in 1958.

Radioactive waste disposal activities in the ORNL pit and trench area have provided contaminated sites for past radioecological terrestrial research. From June 1952 through December 1959, approximately 432,000 Ci of beta activity was pumped into LLW pits 2, 3, and 4 on the ORNL burial grounds north of the WOL bed (Cowser et al. 1960). The inventory of the LLW pit system included approximately 239 kCi $^{103}Ru/^{106}Ru$, 165 kCi $^{134}Cs/^{137}Cs$, 71 kCi transuranic elements, and 41 kCi $^{89}Sr/^{90}Sr$. An estimated 160 Ci ^{106}Ru seeped from these LLW pits onto the lake bed in 1958 plus an additional 1,300 Ci in 1959. About a third of the ^{106}Ru that was discharged to the lake bed in 1959 moved to the Clinch River (Cowser et al. 1960). In early 1962, the estimated ^{106}Ru in the lake bed soils was 2,200 Ci (Lomenick et al. 1962). Trench 5, to the east of LLW pits 2, 3, and 4, first received liquid wastes in June 1960 and eventually received wastes totaling more than 300,000 Ci before being capped in 1966 (Olsen et al. 1983).

Two principal seepage areas where radionuclides had migrated from the waste pits were identified in early radioecology studies associated with the LLW disposal operations (Auerbach 1957). The east seepage area was located in a ravine east of pits 2, 3, and 4 and west of trench 5. The west seepage area was located in a ravine immediately west of pits 2, 3, and 4.

Trench 7 was used for the disposal of intermediate-level liquid radioactive wastes from 1962 to 1966 and received approximately 270 kCi of radioactivity, including fission products, activation products, actinide, and transuranic elements (Olsen et al. 1983). A seepage area located east of trench 7 near well T7-13 is known locally as the "cobalt seep." Concentrations of ^{60}Co in the gravels of the stream that drains this seep exceed 10,000 dpm/g (Spalding and Cerling 1979).

The WOC floodplain south of SWSA 4 was contaminated in 1944 by fission products and transuranic elements when the site served as a temporary impoundment for liquid radioactive effluents from ORNL (Oakes et al. 1982). The impoundment was drained in late 1944, and the total radioactivity in this area in late 1946 was estimated at 68 Ci. An early successional forest developed on the approximate 3-ha site in the 30-year period following drainage of the impoundment. Concentrations of radiocesium and plutonium in floodplain soils are elevated near the old impoundment dam, at the upper portion of the floodplain, and adjacent to WOC (Van Voris and Dahlman 1976; Dahlman et al. 1980). Lower concentrations of radionuclides in soil are found along the lateral perimeter of the floodplain. The highest concentrations of ^{137}Cs are found in the subsoil at a depth of 22-32 cm (8.7-12.6 in).

Detailed biogeochemical studies of uranium, thorium, plutonium, and other transuranic elements have been conducted on the WOC floodplain. The concentrations of $^{239}Pu/^{240}Pu$ in floodplain soil, which ranges from about 10 to 150 pCi/g dry weight over the 3-ha area of the floodplain, is highest in the 0-10 cm (0-3.94 in) zone of the soil profile (Dahlman et al. 1980) The plutonium in the floodplain soil is associated predominantly with clay particles (<2 microns), and the particle size distribution of the soil is more than 70% silt-clay (Tamura 1976). Soil plutonium is most likely in the +IV valence state, predominantly monomeric, surface sorbed, and partly associated with humic material (Bondietti et al. 1976). Plutonium and natural thorium exhibit similar extractabilities from floodplain soil with mild reagent, while uranium is appreciably more extractable (Bondietti and Sweeton 1977). Dahlman et al. (1980) estimated that the total inventory of $^{239}Pu/^{240}Pu$ in the top 20 cm (7.9 in) of soil for the entire 3-ha area was 0.5 Ci.

Radioecological studies carried out over the years at ORNL have provided considerable insights into the availability of radionuclides on the above sites to both terrestrial plants and animals. Auerbach and Crossley (1958) measured ^{90}Sr and ^{137}Cs in native plant species on White Oak Lake bed from 1956 to 1958. These radionuclides were taken up more efficiently by some species than by others, and the higher levels were generally found in leaves than in stems and flowers. The radionuclide inventory in vegetation did not change appreciably during the course of their study. Three species of forage crops planted on the lake bed (Auerbach 1959) also showed highly significant differences among crops in radionuclide uptake, with concentrations of ^{90}Sr and ^{137}Cs being higher in millet and Sudan grass than in fodder cane. Concentrations of ^{90}Sr in millet and Sudan grass were more than twice the ^{90}Sr concentration in the soil in which the forage crops were grown. In subsequent studies (Auerbach 1961), significant reductions in ^{90}Sr, ^{137}Cs, and ^{106}Ru uptake were shown in the field and greenhouse experiments as a result of superphosphate fertilizer treatments.

Analysis of trees from the east and west seepage areas showed high levels of gross beta activity (Auerbach et al. 1957), which was attributed to high concentration of ^{106}Ru reaching the trees through contaminated groundwater. Trees growing in known seepage areas had levels of ^{106}Ru well above those observed for nearby trees that were affected only by aerial contamination (Auerbach and Olson 1963). More recent sampling of tree leaves and groundwaters from the east and west seepage areas has shown the presence of ^{99}Tc, ^{233}U, and ^{60}Co in groundwaters and tree leaves (Olsen et al. 1983). Of these three radionuclides, only ^{99}Tc accumulated to an appreciable extent in forest vegetation. Bondietti and Garten (1986) showed that organic matter in the soil appears to be an important sink for ^{99}Tc in the terrestrial system, although its contribution to the total immobilized fraction remains unquantified.

Few data are available on the exact levels and extent of contamination in herbaceous vegetation and trees growing in the cobalt seep. Tritium and technetium are probably present, based on the levels of groundwater contamination. Wood samples taken in 1985 from maple and sweetgum trees less than 100 m (328 ft) west of trench 7 (at well WT7-3) were found to contain between 50 and 125 pCi/g dry weight (Garten, unpublished data). This contamination undoubtedly results from root uptake of contaminated groundwater, which contained 2,400 pCi/L of ^{99}Tc at well WT7-3.

The studies of vegetation:soil ratios for ^{137}Cs in plant species on the WOC floodplain ranged from 0.001 to 0.53 thirty years after initial contamination, demonstrating that the relative distribution of radiocesium between plants and soil has not changed from distributions reported for the WOL bed 15 years earlier (Dahlman and Van Voris 1976). The relative concentration ratio on a per gram basis averaged 0.03 for vegetation:soil. Average radiocesium concentrations in herbaceous plants, tree leaves, tree wood, and leaffall from the WOC floodplain in 1974 were less than those measured in native vegetation on the WOL bed more than a decade earlier.

DeSelm and Shanks (1963) estimated that approximately 7% and 2% of the soil strontium was removed by lake bed willows and herbaceous communities, respectively. For ^{137}Cs and ^{60}Co, lake bed vegetation was estimated to have removed less than 0.3% of the soil radionuclides. Much of this removal was recycled back into the topsoil as litter.

Studies on the uptake and effects of radionuclides to terrestrial animals and plants at ORNL have focused on invertebrates (especially insects) and small mammals. Studies of insect food chains on the lake bed were initiated in the summer of 1956 (Auerbach 1958) and were continued through about 1964 (Crossley 1969). Concentrations of ^{137}Cs in insects were almost as high as in the plant tissues upon which insects were feeding; however, ^{90}Sr concentrations in insects were nearly an order of magnitude lower than those found in plants (Auerbach 1959; Crossley and Howden 1961). Concentration data for lake bed soil, plants, and insects showed that reduction in the food chain transfer of ^{90}Sr occurred principally at the point of plant-to-insect transfer, while ^{137}Cs movement up the food chain was reduced at the point of soil-to-plant transfer (Crossley and Howden 1961).

Based on uptake-elimination studies, the radiocesium concentration in grasshoppers feeding on contaminated vegetation on the lake bed was expected to rapidly come to equilibrium with concentrations in the vegetation (Crossley and Pryor 1960; Auerbach 1959). Using statistical relationships between the biological half-life of ^{137}Cs and insect body weight, it was estimated that insect consumption was 5% to 6% of the existing plant biomass on the lake bed (Crossley 1963; Auerbach 1961). Crossley (1963) concluded that insects had little effect on the removal and redistribution of radionuclides on the lake bed. In the extreme case, Crossley calculated that if all insects had left the lake bed at one time, the loss of radionuclides would be about 3 Ci each of ^{90}Sr and ^{137}Cs.

Insect communities on the upper portion of the WOL bed were resampled in 1964 near a known source of ^{106}Ru contamination (Crossley 1969). As in previous studies, ^{137}Cs exhibited little plant uptake and a more efficient food chain transfer from plant-to-insect. Both ^{60}Co and ^{106}Ru exhibited higher plant uptake and more efficient transfer from plant-to-insect than ^{137}Cs. Due to the short radioactive half-life of ^{106}Ru (369 d), present-day concentrations of this radionuclide in the upper lake bed soil are estimated at femtocurie/kg levels.

Research on small mammals inhabiting the WOL bed was initiated in December 1957 (Auerbach 1958). The purposes of this research was to study the long-term effects of chronic, low-level radiation (approximately 20 mr/h) on small mammal populations and the uptake of fission products through terrestrial food chains. House mice (Mus musculus) were the predominant small mammal species inhabiting the lake bed in late 1956 and early 1957. This species was replaced by cotton rats (Sigmodon hispidus) and rice rats (Oryzomys plaustris) during late 1957 and early 1958 (Auerbach 1958).

Estimated dose rates from internal and external radioactivity for cotton rats inhabiting the lower lake bed in 1960 were initially approximated at 3 rems/wk (Kaye and Dunaway 1963). Most of the dose (approximately 70%) from internally deposited radionuclides arose from the accumulation of ^{90}Sr. Estimated lifetime doses for small mammals on the lake bed from the external radiation field were approximately 60 rems (Kaye and Dunaway 1963). Further studies with rats bearing subcutaneous glass rod dosimeters showed that the average absorbed daily dose rate was between 1 and 3 rads/d (Auerbach 1963). Despite the increased levels of internal and external exposure, Dunaway and Kaye (1963) concluded from their studies of small mammal populations that the effects of ionizing radiation on mammals from the lake bed were not discernible. Although the average litter size of cotton rats on the lake bed was smaller than in uncontaminated areas, the survival of the rats on the lake bed was better than that in reference areas. Also, there was less incidence of lesions and other pathological conditions in white-footed mice from the lake bed in 1960 than in mice from uncontaminated areas (Dunaway and Kaye 1963). Possible effects of lake bed radiation on cotton rat weights, breeding condition (Dunaway and Kaye 1964), and hematology (Auerbach 1963) were not unequivocally demonstrated. In similar studies of cotton rats, white-footed mice, and rice rats (Childs and Cosgrove 1966) from the WOL bed, the levels of radiation exposure were found to be too low to result in somatic effects on small mammals. Pathologic and parasitologic findings appeared to be coincidental to radionuclide contamination of the environment, but no causal relation was postulated.

Concentrations of ^{90}Sr in small mammals inhabiting the lake bed were 35 times higher than those found in birds (Auerbach 1960). Similarly, based on concentration data and measurements of population densities, Kaye and Dunaway (1962) estimated that body burdens of ^{90}Sr in small mammals was considerably higher than body burdens of ^{90}Sr in birds on the lake bed.

Studies on the uptake of fission product radionuclides by birds frequenting the lake bed during 1958 and 1959 (Willard 1960) showed that birds feeding close to the ground (sparrows, thrushes, and chats) exhibited the highest levels of gross beta activity in body tissues (exclusive of feathers and Gastrointestinal tract). The concentration of ^{90}Sr in bird bones was about six times greater than that of

^{137}Cs in bird muscle. Higher concentrations of ^{90}Sr and ^{137}Cs in birds during the winter were attributed to the direct ingestion of contaminated soil as a result of birds probing the soft soil for plant seeds. Willard (1960) estimated the amount of ^{90}Sr and ^{137}Cs in birds occupying the lake bed to be 640 Bq/ha (7 nCi/acre) and 1736 Bq/ha (19 nCi/acre), respectively; thus, the total amount of radioactivity which was at risk of removal through migration was considered negligible, approximately 7,400 Bq (0.2 µCi) to 22,200 Bq (0.6 µCi) for the entire lake bed. However, the maximum observed levels of ^{90}Sr in bird bones exceeded the concentration that is permissible in humans (Willard 1960).

3.4.2.2 Surveys of Terrestrial Biota

Extensive information exists on the terrestrial flora and fauna of DOE Oak Ridge Reservation, including that of the WOC watershed (e.g., see Krumholz 1954a; Johnson 1964; Olson et al. 1966; Grigal and Goldstein 1971; Mann and Bierner 1975; Anderson et al. 1977; Johnson et al. 1979; Bradburn and Rosenbalm 1984). The vegetation of undeveloped portions of the ORNL site is similar to the vegetation of the Oak Ridge Reservation as a whole (Boyle et al. 1982), which is described by Kitchings and Mann (1976), Dahlman et al. (1977), and DOE (1980). The occurrence of threatened and endangered species on the Oak Ridge Reservation and the distribution of plant communities (and the fauna associated with them) have been described by Kitchings and Mann (1976). Recent information on threatened and endangered species on the Reservation is provided in Boyle (1982), Kitchings and Story (1984), and Parr (1984a, 1984b).

The Oak Ridge Wildlife Management Area was established on the Oak Ridge Reservation in November 1984 under a cooperative agreement between DOE and the Tennessee Wildlife Resources Agency. A series of organized public deer hunts were established for the first time in 1985 to reduce the number of deer-vehicle collisions and to provide recreational hunting . In late 1985, several wild turkeys were released on the Oak Ridge Reservation as part of an effort to establish turkey populations in several areas of the state.

4. ADDITIONAL INFORMATION NEEDED

The purpose of this section is to describe the additional studies needed to achieve the level of characterization required to establish source terms, model surface and subsurface water movement and contaminant transport, and identify potential pathways. It appears that the major pathway for contaminant transport from the WOC/WOL watershed is by surface flow through WOD to the Clinch River; however, subsurface flow under or around WOD represents a possible pathway which must be evaluated. Figure 13 shows the work elements involved in this characterization plan.

Although a large amount of background information has been collected on the WOC watershed (Sect. 3 and Appendix A), much of this information has resulted from short-term site evaluation studies or problem-oriented hydrologic or ecologic projects rather than from detailed characterization of the subsurface materials and hydrologic and ecologic conditions in the floodplain. Thus, considerable additional characterization information is needed. It is logical to expect that some of the studies outlined below will have to be revised as the results of initial data collection become available; however, sufficient flexibility has been built into the proposed studies to allow for reasonable modifications or alternative approaches, if necessary.

4.1 CONTAMINANT INVENTORY

The additional contaminant characterization activity needed is the compilation of a data base on the types, levels, and quantities of contaminants moving into or out of the floodplain in surface or groundwater flow, or accumulating in the sediments in the flood plain. The major effort in this task is the development and maintainance of a computerized data base. Some of the information to be entered into this data base already exists (Appendix A, Sect. A3.1 and A3.3). Integrating this existing information with the contaminant data collected in the planned geologic, hydrologic, and ecologic studies,

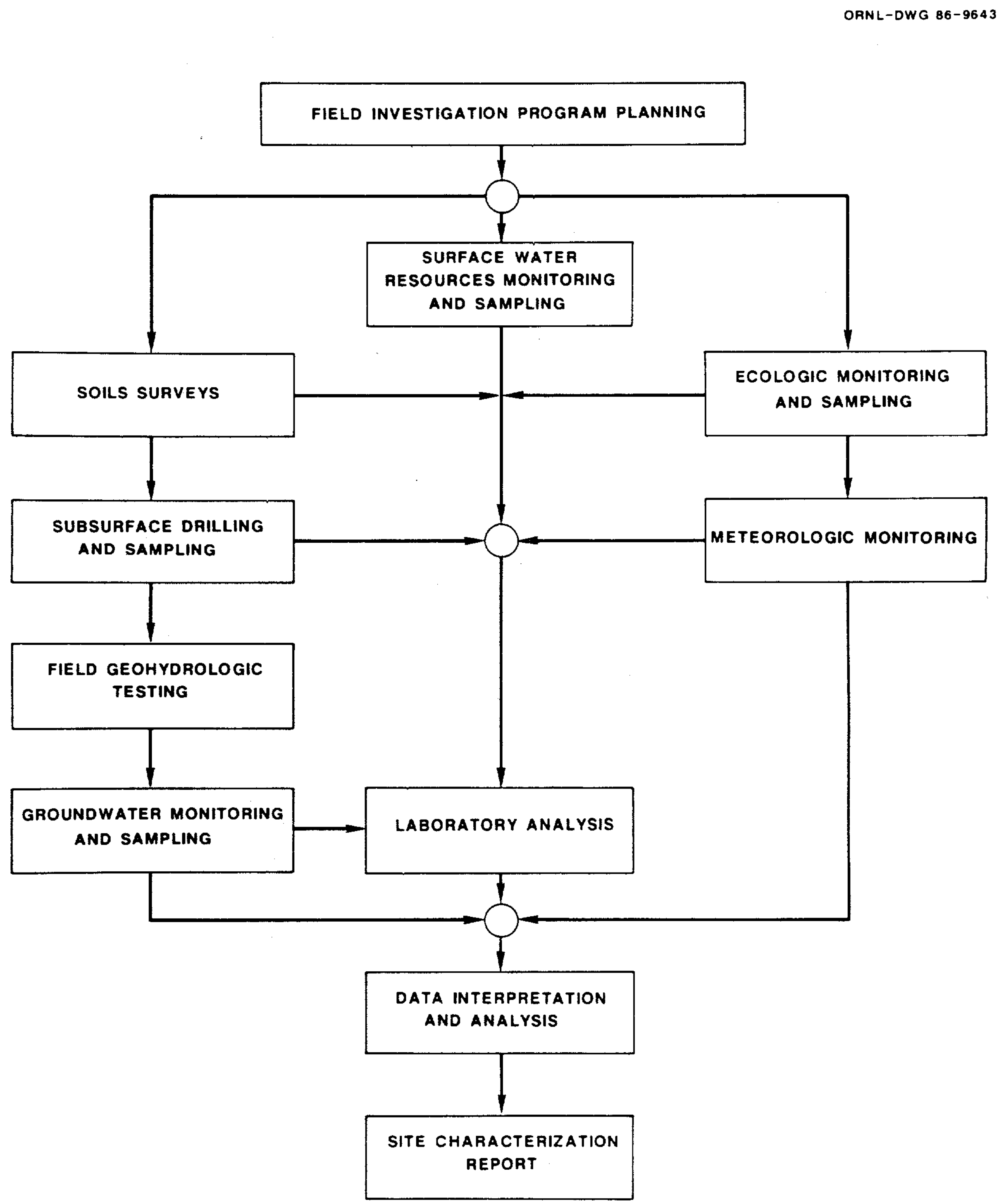

Fig. 13. Generalized elements of a site characterization.

and the results of long-term NPDES and environmental monitoring, will provide the basis for estimating source terms to be used in future modeling and remedial action analyses.

4.2 GEOLOGY AND SOILS

Considerable information on the geology and soils of the WOC/WOL watershed has been collected in conjunction with previous studies of laboratory facilities and waste storage areas; however, very little of these data fall within the WOC/WOL floodplain. Data needs within this area will mainly be met by exploratory drilling and by evaluation of cores and cuttings from wells drilled as a part of the planned groundwater studies (Sect. 4.3). It is also apparent from reviewing the existing information that detailed geologic data in the vicinity of WOL and WOD is crucial to understanding and quantifying the possible movement of contaminants in groundwater around and under WOD.

4.2.1 Geology

Considerable geologic information will be collected and analyzed in conjunction with drilling conducted to delineate and test permeable zones which may provide pathways for the movement of groundwater and contaminants into the creek or lake and around or under the dam. All drilling needed to confirm the potential for water movement under and around the dam, and wells required for the proposed groundwater studies, will be described later in the groundwater section (Sect. 4.3.3).

Lithologic logs from studies in waste storage areas adjacent to the WOC/WOL floodplain strongly suggest the presence of permeable zones in joints and fractures caused by geologic deformation in the formations underlying the floodplain. Although drilling logs are not available to confirm the existence of such zones or to indicate the depths at which they may occur, several likely zones of increased porosity and permeability are indicated: (1) the shallow zone of soil and weathered and unweathered rock near the water table; (2) a zone of increased deformation in the upper Maryville Limestone; (3) contacts between limestone and shale units which tend to localize solution cavities--in the WOL area the contacts between the Maryville Limestone and the Nolichucky and Rogersville shales; and (4) possible faults which may act as conduits for groundwater.

Primary geologic information for characterization of the lower floodplain will be obtained by the evaluation of cores and geophysical logs from six core wells drilled to depths of 182.9 to 243.8 m (600 to 800 ft) in the vicinity of WOL and WOD (Fig. 14) as part of the studies to evaluate the occurrence and movement of groundwater (Sect. 4.3.3). Information on the areal variation in shallow subsurface materials, those less than 30.5 m (100 ft) deep, will be acquired by evaluating cuttings collected during drilling associated with the installation of 60 piezometers. The piezometers will be used to monitor water levels and gradients in the floodplain and for water quality sampling to evaluate the movement of leachates from the waste storage areas into the floodplain and the surface-flow system.

Additional geologic site characterization activities needed include the following:

- examination of cores and rock cuttings taken during the drilling of the six core holes and the installation of 60 piezometers to provide geologic detail and detect zones of possible groundwater flow, and
- physical, chemical, and radionuclide characterization of the drill cuttings and cores to determine the composition of the subsurface materials and evaluate the potential mitigation of contaminant movement by these materials.

4.2.2 Soils

Soil erosion is the main source of sediments in WOC and WOL. Soils and sediments can also act as a sink for radionuclides through adsorption of waterborne radionuclides. Soils in the WOL floodplain will be surveyed at a scale of 1:15840 and classified to the "Soil Series" level of the soil classification system. Soils in the area are

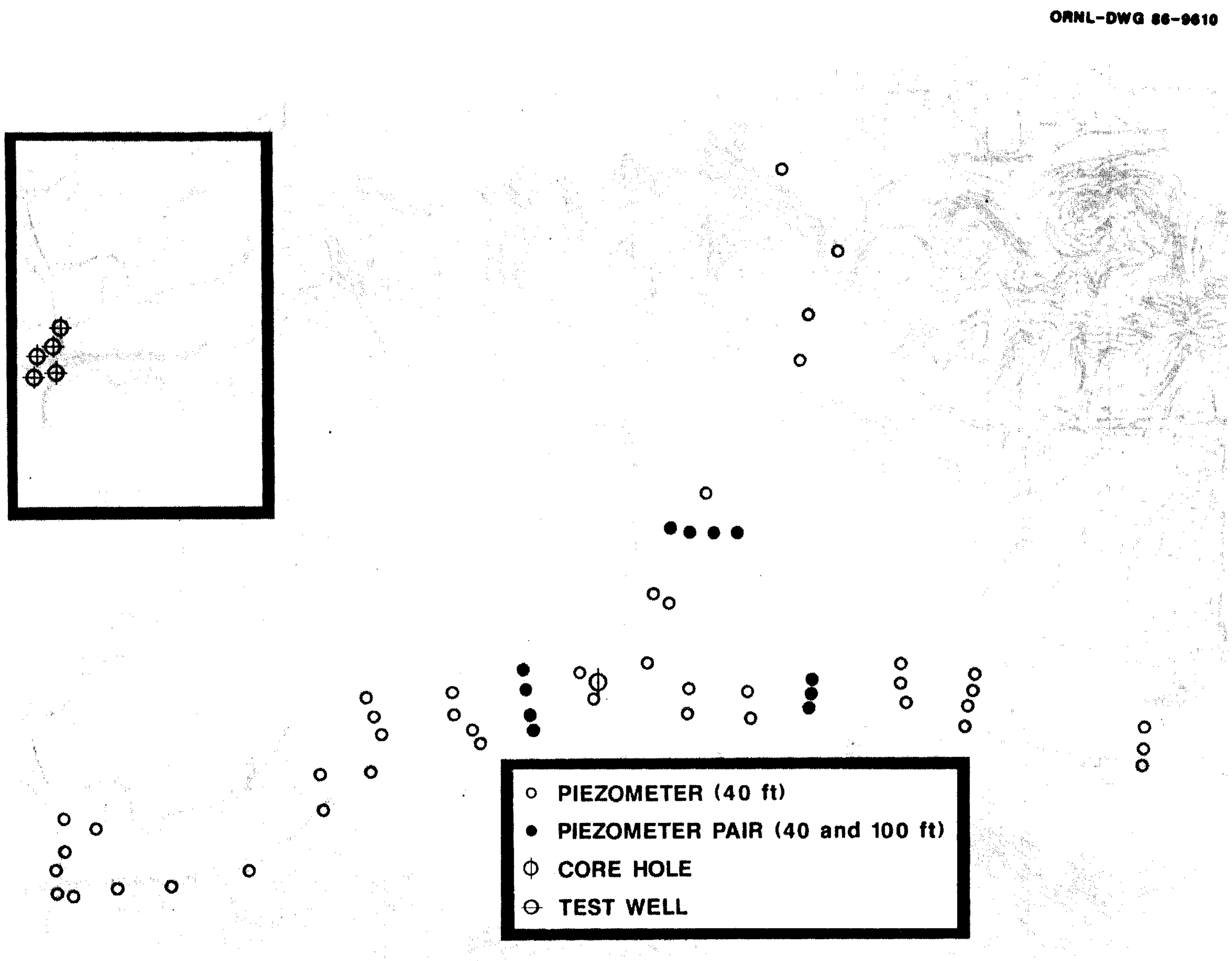

Fig. 14. Location of piezometers, core holes, and test wells in WOC/WOL floodplain.

developed from Conasauga, Rome, Chickamauga, and Knox Groups and their alluvium and colluvium. About 35 soil series are expected to be present in the area. Through the soil survey and mapping, dominant soil series will be identified and grouped together based on the similarity of their morphological, physical and engineering, chemical, and mineralogical properties. To support soil classification and hydrological investigation of the watershed, laboratory-oriented characterization of the representative soil groups (about 15 soil profiles) will be performed. Soil physical and engineering properties to be determined include shrinking-swelling potential, liquid limit, plastic index, texture, porosity and bulk density, permeability, and erodibility factor. Chemical and mineralogical properties include acidity, cation exchange capacity (sorption properties), and mineralogical composition.

A survey of surface radiation will be conducted on the lower floodplain to delineate areas of elevated radioactivity. The areas of elevated radioactivity in the floodplain are believed to be caused by past deposition of contaminated sediment or runoff and seeps from SWSAs and the pits and trenches. A beta-gamma radiation survey will be a primary approach for locating and delineating contaminated areas. Selected soil samples will be analyzed for alpha radiation (transuranic radionuclides). The objective of the radiation survey is to understand the extent of surface contamination and the location of contaminant sources to WOC and WOL. Some of the contaminated soils will be leached to estimate migration potential of the radionuclides in soils.

Additional soil site characterization activities include:

- o soil survey and mapping of the lower WOC floodplain [approximately 55.7 x 10^4 (6 x 10^6 ft^2)],
- o determination of physical and engineering, chemical, and mineralogical properties of representative soils in the basin, and
- o estimation of radionuclide contamination in the surface soils and assessment of their migration potential.

4.3 HYDROLOGY

WOC and its tributaries drain the ORNL complex as well as the waste storage areas associated with long-term Laboratory operations. In addition to natural flow, WOC receives the treated and untreated effluent from Laboratory facilities and leachates and runoff from waste storage areas and surface spills throughout the watershed. Hydrologic data, especially streamflow and water quality, has been collected throughout the watershed since the beginning of Laboratory operations; however, the scope of the background information on groundwater-surface water interactions and the movement of contaminants in the integrated flow system is limited. Thus, the collection and evaluation of hydrologic data on the quantity and quality of water moving through the surface and groundwater flow system constitutes a major part of the characterization plan. Hydrologic site characterization activities should include compilation of a hydrologic data base and preparation of an annual release of the data collected. The first release should include historical data.

4.3.1 Climate

Climatic factors play a dominant part in determining the hydrologic characteristics of the WOC watershed. Precipitation largely controls the amount and variations in streamflow, and wind, temperature, and humidity greatly influence evapotranspiration. Meteorological data for the watershed are needed primarily for the determination of water budgets, analysis of the airborne pathway, and analysis of the magnitude and frequency of floods. For purposes of site characterization, hydrologic modeling, and flood predictions, monitoring efforts should be focused on the amount and frequency of rainfall, wind direction and velocity, temperature, and humidity.

Additional activities needed include the following:

- correlate short-term climatological data in the watershed with the long-term record at the Oak Ridge National Oceanic and Atmospheric Administration station;

- integrate current and historical meteorological records to establish a readily available data base for the existing precipitation monitoring sites in the watershed; and
- continue collection and compilation of data on precipitation, wind velocity and direction, temperature, and humidity at Tower C in Bethel Valley, on precipitation at SWSA 5, and on precipitation, temperature, and humidity at either the EIPCOR or ETF site in SWSA 6.

4.3.2 Surface Water

Because the WOC flow system drains all of ORNL and the waste storage areas, flow through WOD to the Clinch River is probably the primary pathway of contaminant movement from ORNL. Therefore, characterization of streamflow and the contaminants conveyed in the water and suspended sediment, as well as in the sediments deposited in WOL, is a primary objective. Because of the large number of contaminant sources, the nature of the contaminants, and conditions in the flow system, considerable hydrologic data are needed. Monitoring of some parameters will be required on a long-term basis.

4.3.2.1 Stage and Flow

Monitoring of stage and flow in the WOC-WOL flow system, especially at WOD, is essential for characterization purposes and for determining the quantities of contaminants entering the surface flow system and flowing through the dam to the Clinch River. Flood flow measurements at the dam are especially important for the analysis of the effects of scouring and movement of WOL sediments through the dam.

Additional activities needed include the following:

- Continue monitoring of stage and flow at WOD on a continuous basis (in conjunction with NPDES contaminant monitoring and sampling) to determine current and long-term variations in discharge from the lake and watershed. Maintain existing continuous stream monitoring stations in conjunction with water quality sampling to identify and quantify contaminants entering WOC from laboratory facilities, SWSAs, and spills.

- Measure flow and stage (MSL datum) on 10 unmeasured tributaries to WOC/WOL (Fig. 15) periodically (semiannually) to aid in locating and quantifying contaminant sources. Small weir-type flow measurement stations will be established to permit measurements under varying flow conditions.
- Conduct field studies of groundwater inflow and outflow in selected reaches of WOC and its tributaries in connection with streambed gravel studies (Sect. 4.3.2.2) and sampling to detect contaminant inflow/outflow. Gain or loss of flow in the selected stream reaches will be determined by upstream and downstream flow measurements and by use of groundwater gradients and aquifer permeabilities measured in nearby observation wells.

4.3.2.2 Chemical Quality

Water quality data is required to characterize the surface flow system, to determine the sources and nature of contaminants entering the system, and to provide the source term for the analysis of movement of contaminants off the reservation through WOD. Background water quality data is also needed for stream reaches near the headwaters of WOC upstream of known sources of contaminants.

Continuous monitoring of radioactivity and selected chemical parameters at the dam, at several instream sites, and at Laboratory effluent release points by the ORNL environmental and operational monitoring program (Sect. 3.3) is especially important to indicate changes in point discharge or leachate sources.

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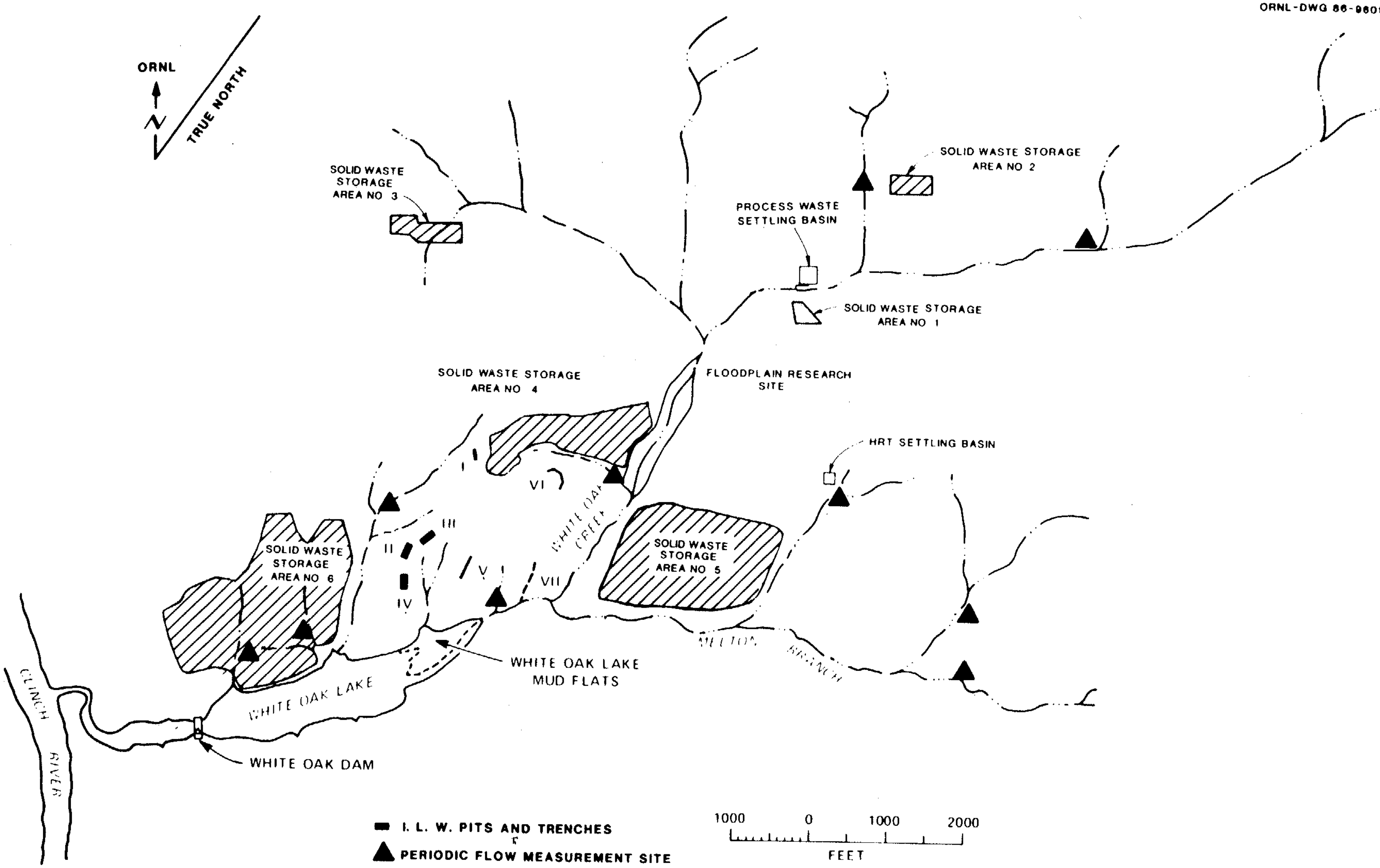

Fig. 15. Location of proposed periodic flow measurement sites.

Additional activities for surface water quality assessment include:

- Continue monitoring radioactivity and sampling for selected radionuclides and nonradioactive contaminants in flow at WOD on a continuous basis (weekly analysis of composite samples for radionuclides and selected NPDES constituents in solution and in suspended sediments). Sample for radionuclides and selected metals and organics semiannually at existing flow-monitoring stations to identify and quantify contaminants entering the flow system from Laboratory facilities, SWSAs, etc.
- Sample for radionuclides and selected chemical constituents (Table 10) at the 10 tributary sites and the new inflow/outflow measurement sites (Sect. 4.3.2.1) semiannually in order to determine concentrations and estimate quantities of contaminants entering the flow system from specific sources.
- Sample for radionuclides and metals and organics semiannually in WOC downstream from WOD.
- Continue sampling stream bed gravel for ^{137}Cs, ^{90}Sr, and ^{60}Co at selected sites on a annual basis to aid in determining changes in radionuclide sources.

4.3.2.3 Contaminants in Sediments

The long-term accumulation of sediments in the bed of WOL is the largest source of contaminants in the floodplain. The possibility for movement of large quantities of contaminated sediment through WOD during flood periods, as well as the possibility of direct exposure or airborne transport of contaminants if the lake is drained, make the sediment bed a major factor in consideration of remedial action alternatives. Knowledge of the nature and concentrations of the contaminants and the volume and distribution of the sediment bed is essential to the characterization of the flow system, development of a source term, and the planning of any needed remedial measures.

Table 10. Typical parameters for White Oak Creek/White Oak Lake instream contaminant analysis

Parameter
Field analysis
Dissolved oxygen
Temperature
pH
Conductivity
Alkalinity
Laboratory analyses
Turbidity
Total suspended solids
Total volatile suspended Solids
Hardness
Nutrients:
(a) NH_3-N
(b) NO_2+NO_3-N
(c) Total Kjeldahl N
(d) Total P
Oil and grease
Priority pollutants[1]:
(a) Volatile organics
(b) Base/neutral compounds
(c) PCBs
(d) Cyanide
(e) Total phenol
Priority pollutant metals (As, Be, Cd, Cr, Cu, Pb, Tl, Ni Ag, Zn, Sb, Se):
(a) Total
(b) Dissolved
Radiological analyses
(a) Gross alpha
(b) Gross beta
(c) Gamma spectroscopy
(d) Tritium (^3H)
(e) ^{137}Cs, ^{60}Co, ^{106}Ru ^{125}Sb, ^{90}Sr, ^{238}Pu ^{239}Pu, ^{99}Tc, ^{237}Np, ^{232}Th and ^{228}Th, ^{238}U, ^{234}U, ^{235}U, Zm_{65}
Aluminum
Mercury
Total
Dissolved

[1]Scan for organics; extended analysis if justified.

Additional activities needed include the following:

- o Collect and analyze core samples for contaminants in bottom sediments in WOL and selected reaches of WOC and MB. Approximately 60 core samples and detailed chemical and radiological analysis will be required to adequately categorize the nature, constituent levels, volume, and distribution of the current sediment bed.
- o Using the flow over over WOD (Sect. 4.3.2.1) and the results of the chemical and radiochemical analysis of the suspended sediments (Sect. 4.3.2.2), determine the load of contaminants in sediments flowing out of WOL under varying flow conditions (especially very high flow).

4.3.3 Groundwater

Few data are available on groundwater movement in the floodplain (especially at depth). Because groundwater flow is reported to convey much of the contaminant load into WOC and WOL from waste storage and disposal areas, and is also a possible pathway for flow of contaminants around and under WOD, it is imperative that adequate data on groundwater occurrence, movement, and quality be collected and analyzed for characterization purposes and to evaluate groundwater flow and contaminant levels in permeable zones in the formations underlying the floodplain.

4.3.3.1 Occurrence

Although no deep wells have been drilled in the lower floodplain to determine the depth, thickness, and water-bearing characteristics of the subsurface formations, drilling in the same formations in adjacent areas strongly suggests the presence of permeable water-bearing zones in the upper 243.8 m (800 ft) of these materials. Water-bearing zones are likely to occur (1) in the shallow zone of weathered rock of the Nolichucky Formation near the water table, (2) in fractures, joints and solution channels at the contact between the Nolichucky Formation and the underlying Maryville Limestone, and (3) in fractures and joints at the contact between the Maryville Limestone and the underlying Rogersville shale.

The following groundwater activities are planned to detect and test water-bearing zones for characterization of the groundwater flow system and the evaluation of contaminant pathways into and out of the floodplain.

- Evaluate cuttings, cores, and well logs from three deep wells currently being installed in the floodplain to aid in drilling and testing the core holes and test wells listed in the next item.
- Drill six core holes, 182.9 to 243.8 m (600 to 800 ft) deep, and 12 to 15 test wells, 61 to 243.8 m (200-800 ft) deep, in the vicinity of WOD and the downstream reach of WOC (Fig. 14) to identify permeable zones through which water and contaminants may flow around or under the dam. Wells will be drilled in clusters of three at each site, bottomed at different depths to isolate permeable zones, and used for head measurements, water sampling, and aquifer tests.

4.3.3.2. Water Level Fluctuations and Gradients

A network of water table wells (referred to MSL datum) will be required to permit measurements of water levels and preparation of water level contour maps to show the configuration of the water table in the floodplain, and to aid in determining groundwater gradients and flow patterns in the shallow permeable zones which appear to extend from the adjacent waste storage areas. Water level fluctuations in these wells and fluctuations in wells in deeper zones will be analyzed to aid in determining the degree of interconnection between different water-bearing zones in the formations underlying the floodplain.

Additional activities needed include the following:

- o Install approximately 60 piezometers, 10.7 to 30.5 m (35 to 100 ft) deep, in the floodplain (Fig. 14) for water level measurements. Drill cuttings from these wells will be examined for lithologic logs and analyzed for contaminants as a part of the activities discussed in Sect. 4.2.1.
- o Measure water levels in the piezometers and prepare water table contour maps (MSL datum) to show the configuration of the water table, water level gradients, and inferred directions of groundwater flow. Measure water level in wells drilled to different depths near WOD (Sect. 4.3.3.1) and prepare vertical and horizontal flow nets to describe flow around and under the dam.
- o Install continuous water level recording gauges on approximately 10 wells of various depths in the floodplain to establish water level characteristics in different areas, at different depths, and during different seasons.

4.3.3.3 Aquifer Tests

The capacity of the water-bearing zones in the formation underlying the floodplain to transmit and store water must be determined to characterize the groundwater flow system and to provide a basis for modeling and pathways analysis. Primary permeable zones will be tested by pumping tests involving drawdowns in several wells in one or more zones. Most wells will be tested individually for hydraulic conductivity by raising or lowering water levels and measuring recovery with time.

Additional activities needed include the following:

- o Drill approximately 10 shallow, 6.1- to 15.2-m (20- to 50-ft), wells, and 10 deep, 15.2- to 121.9-m (50- to 400-ft) wells for aquifer tests in the shallow weathered rock and in deeper permeable zones detected by wells drilled as described in Sect. 4.3.3.1.

- o Conduct aquifer tests to determine the aquifer characteristics (transmissivity and storage coefficients) of the Chickamauga Group in Melton Valley by pumping one well and measuring water level declines in nearby wells bottomed in the same zone.
- o Conduct hydraulic conductivity tests in the 60 piezometer wells (Sect. 4.3.3.2) and the deep test wells at WOD (Sect. 4.3.3.1).
- o Consider conducting tracer tests to aid in determining aquifer properties and the rate and direction of groundwater flow in the vicinity of WOD.

4.3.3.4 Water Quality

Information on the quality of groundwater in the water-bearing zones of the formations underlying the floodplain is essential for the characterization of the flow system and detecting the movement of contaminants into the floodplain from waste storage areas, inflow/outflow of contaminants to and from the surface flow system, and the movement of contaminants in groundwater flow in the vicinity of WOD. The following drilling and sampling activities are needed:

- o In addition to the wells described in Sects. 4.3.2.1 and 4.3.2.2, approximately 30 monitoring wells will be installed in the floodplain downgradient of the waste storage areas or Laboratory discharge points where groundwater contaminants are detected. These wells will monitor contaminant movement in permeable zones, 6.1 to 61 m (20 to 200 ft) deep, towards the creek and lake. Samples will be collected and analyzed for selected radionuclides, metals, and organics on a semiannual basis (wet and dry season) (Table 10).
- o Sample test wells and piezometers in the floodplain to provide: (1) detailed data on contaminants entering WOC, WOL, and MB in groundwater from sources such as SWSAs, pits, and trenches, etc., in areas identified by streambed gravel studies, surface water sampling, or seeps, and (2) detailed data on contaminants in groundwater flow around and under WOD. Initial samples from all wells and piezometers will be analyzed for key constituents selected as indicative of contamination (Table 10).

4.4 ECOLOGY

Although much is known about the types and relative amounts of radionuclides in the WOC watershed, additional information is needed to adequately scope potential environmental and human health problems associated with these contaminants. Existing guidelines (EPA 1985) suggest that data collected during initial site characterization studies should include, inter alia, environmental concentrations and potential impacts on receptors, including both the human populations and the environmental systems susceptible to contaminant exposure. Before an analysis of the potential for human or environmental exposure can be initiated, however, those contaminants on which such an analysis will be based must be identified (EPA 1985). Consequently, a screening exercise will be performed, using existing data, to identify potential critical pathways for human exposure. With few exceptions, transfer coefficients for radionuclides to terrestrial plants and animals, relative to soil and water, are quite low; thus, systematic soil surveys of floodplain areas for radionuclides followed by application of existing transfer coefficients will be used to provide estimates of contaminant levels in terrestrial biota. These calculations will be supplemented, as appropriate, with residue analyses of animals and vegetation.

A similar screening will be conducted on WOL to identify critical aquatic pathways for human exposure and to identify problem radionuclides. Existing data on radionuclide concentrations in sediments, water, and biota will be used initially; as necessary, additional information will be collected to determine the current radioecological status of WOL. For example, a detailed inventory of the sediments that includes all radionuclides (fission products and transuranic elements) that have been released and are still detectable is needed . The results of these screening exercises to identify critical terrestrial and aquatic pathways will determine the need for additional studies during the remedial investigation phase. Such studies could address, for example, those radionuclides for which insufficient data are available to predict transfer coefficients or those that demonstrate ready availability to biota plus incorporation into tissues.

In addition to the human health effects of exposure to radiological contaminants, data are also needed to address the environmental effects of nonradiological organic and inorganic contaminants. Assessment of both human health and environmental effects will be included in the ORNL Biological Monitoring Plan and Abatement Program (BMPAP). As a condition to the NPDES permit for ORNL (EPA 1986), a plan for biological monitoring of the Clinch River, WOC, Northwest Tributary, MB, Fifth Creek, and First Creek must be submitted to the EPA and the Tennessee Department of Health and Environment within 90 d of the effective date of the permit (April 1, 1986). The plan, referred to in Part III (H) of the permit as the Biological Monitoring Plan and Abatement Program, describes characterization monitoring studies to be conducted for the duration of the permit (5 years).

The BMPAP will provide not only the data to assess radioecological effects, as outlined previously, but also the data to demonstrate that the effluent limitations established for ORNL, as outlined in the NPDES permit, protect and maintain the classified uses of WOC and MB. Such uses include (1) growth and propagation of fish and aquatic life and (2) livestock watering and wildlife utilization (TDPH 1978). The BMPAP will also provide ecological characterizations of WOC and selected tributaries and WOL that can be used to (1) document ecological impacts of past and current operations, (2) identify contaminant sources that adversely affect stream biota, and (3) provide baseline data that can be used to determine the effectiveness of remedial actions, including implementation of a Water Pollution Control Program at ORNL. The BMPAP consists of seven major tasks: (1) toxicity monitoring, (2) bioaccumulation of nonradiological contaminants in aquatic biota, (3) biological indicator studies, (4) instream monitoring of benthic invertebrate and fish communities, (5) assessment of contaminants in the terrestrial environment, (6) radioecology of WOL, and (7) contaminant transport, distribution, and fate in the WOC embayment-Clinch River-Watts Bar Reservoir system. Although included as part of the BMPAP, the latter three tasks, as described previously, will also satisfy the data needs related to RCRA remedial action activities for WOC and for WOL. Detailed descriptions of each of the seven tasks are given in Loar et al. (in preparation).

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APPENDIX A

REVIEW OF EXISTING INFORMATION ON THE WHITE OAK CREEK WATERSHED

Since 1943, a significant Research and Development (R&D) effort has been devoted to evaluating the impact of ORNL low-level waste (LLW) disposal operations on the White Oak Creek (WOC) watershed. Most of these studies have been undertaken to (1) evaluate the effectiveness of existing LLW disposal operations, (2) improve operations, (3) locate new disposal facilities, and (4) conduct ecological studies related to the accumulation and transport of radionuclides in aquatic and terrestrial ecosystems. The results of these investigations are reported in numerous open literature and Laboratory reports. This appendix has been prepared to summarize the findings in many of these R&D studies to provide background information for development of a corrective measures plan.

A.1 CONTAMINANT INVENTORY

Studies of the WOC watershed (Dahlman and Van Voris 1975, Spalding and Cerling 1979, Oakes et al. 1982) have identified several locations of sediment contamination, the most significant of which are the bed of White Oak Lake (WOL) and the floodplain area adjacent to Solid Waste Storage Area 4 (SWSA) (Fig. 2). In addition to these two major contaminated sediment locations, a number of areas or sites have been identified, including the stream bed downstream from the intermediate hold-up pond, operational facilities in the Laboratory, the drainage area for the former Homogeneous Reactor Experiment (HRE), and the drainage areas for the SWSAs and LLW pits and trenches that represent potential sources of contamination movement into the watershed. A number of studies have been conducted to detect and quantify the downgradient movement of contaminants from the waste storage areas, and a variety of remedial measures have been undertaken.

During 1978-79 SWSA 3 (Fig. 2) was shown to contribute an average of 6.4 mCi/month of ^{90}Sr to the northwest tributary of WOC by groundwater flow to a seep in a 30-m reach of the tributary about 350 m from the disposal area (Stueber et al. 1981). The groundwater flow path was apparently through solution channels running parallel to the bedding strike. Contaminant concentrations in the tributary have decreased since that time, possibly because of the diversion of runoff around the site and improved covering of the area.

High groundwater levels at SWSA 4 have resulted in radionuclide transport within the burial area with the development of a number of "seeps" near the lower portion of the SWSA. SWSA 4 contributes approximately 35 to 50% of the ^{90}Sr discharged annually from the WOC basin at White Oak Dam (WOD). It has also been estimated that nearly 90% of the ^{90}Sr discharged from SWSA 4 is associated with stormflow (Huff et al. 1982). Recent studies suggest that considerable radionuclide transport involves the bathtub effect, where trenches collect water faster than it can drain away, resulting in overtopping of the trench at the lowest point along the rim. In extreme cases, positive pressure develops within the trench, and the leachate is discharged as an artesian spring, primarily during storms.

In an effort to decrease the impact of water intrusion, a surface runoff collector and diversion system was constructed in 1975 to divert water across the site. The diversion system carries large amounts of water during heavy rains and small amounts of water for several days afterwards. In addition, a second surface water diversion project was undertaken in 1983 in an effort to channel the flow from the area north of the burial ground around the site rather than through it. Evaluation of the effectiveness of this diversion is currently under way, and early indications suggest a significant reduction in ^{90}Sr releases to WOC (Melroy and Huff 1985).

SWSA 5 has been a significant contributor of ^{3}H to WOC. Normal problems caused by infiltration of precipitation were aggravated in SWSA 5 because of poor trench orientation. Trenches in this burial ground were excavated with their long axes downslope, paralleling the hydraulic gradient of the water table. As a result, some of these trenches filled with water that seeped out the lower ends of the trenches. In 1975, corrective actions were taken to reduce the seepage in an area found to have relatively high amounts of ^{90}Sr and measurable amounts of ^{244}Cm and ^{238}Pu (Duguid 1976). Initially, about 06 m (2 ft) of overburden was removed from the area overlying four of the burial trenches. Two underground dams, one of concrete and one of bentonite-shale, were then installed across two parallel trenches. The stripped area was covered with a Polyvinyl Chloride (PVC) membrane, and the overburden was replaced. In addition to the placement of subsurface dams and PVC membrane in SWSA 5/south, a near-surface seal consisting of a bentonite-shale mixture was placed over 14 trenches in the Transuranic (TRU) waste area (SWSA 5/north) to prevent excessive infiltration of precipitation. Other corrective measures taken in SWSA 5 include filling of collapsed trench caps, installation of concrete drainage ditches, and surface contouring for better drainage. Data on contaminants (other than ^{3}H), entering the surface flow system from SWSA 5 are sparse; however, the ORNL radioactivity monitoring stations in Melton Branch upstream and downstream of SWSA 5 show a consistent increase in ^{90}Sr levels of as much as 20 mCi.

High levels of both ^{3}H and ^{90}Sr have been reported in a tributary that drains SWSA 6 to WOL (Spalding and Cerling 1979). Water samples collected during 1981 showed ^{3}H concentrations as high as 20,000 Bq/L (Vaughan et al. 1982), and streambed gravel samples showed ^{90}Sr concentrations of more than 220 Bq/kg in 1978 (Cerling and Spalding 1981) and 690 Bq/kg in 1985 (personal communication, T. E. Cerling 1986). Periodic water table measurements in SWSA 6 indicated the presence of shallow groundwater in an isolated area known as the 49-Trench area, a small subsection of SWSA 6 containing 49 LLW disposal trenches that were filled with waste and closed in 1973-74. In an attempt to prevent rainfall from infiltrating the cover material and collecting in the trenches, this area was sealed with a bentonite cover in 1976 (Tamura et al. 1980). Despite this cover, water still collected in the underlying trenches. Hence, a second engineered barrier, consisting of a French drain designed to prevent the lateral movement of groundwater into the trenches (Davis and Stansfield 1984), was installed in 1983. The drain was installed at a depth of approximately 9.1 m (30 ft), surrounding the group of trenches on the north and east sides. Early monitoring activities have shown the dewatering of several trenches close to the drain, as well as a more general lowering of the groundwater table.

To date, very little sampling and analysis for nonradioactive contaminants in groundwater in the SWSAs have been conducted. Most of the existing wells were not designed or installed in accordance with current requirements for monitoring wells, and the available analyses do not provide significant information on the potential for contamination transport to WOC from this source. Chemical analyses have been reported that indicate that samples from some of the wells in the SWSAs downgradient from the main storage areas and close to WOL were contaminated with a variety of pollutants (Martin Marietta Energy Systems, Inc. 1985).

From 1951 to 1966 seven seepage pits and trenches were used for the disposal of liquid low-level wastes at ORNL (Lomenick et al. 1967). These waste pits and trenches were located on ridge tops in Melton Valley south of SWSA 4. The three initial disposal sites were open pits excavated in the weathered Conasauga Group. Because of concern with radiation fields surrounding these open pits, trenches 4 to 7 were excavated and backfilled with crushed limestone to enhance drainage and were covered with compacted earth to reduce radiation intensity. Waste liquids (adjusted to a pH of 12 with NaOH) were allowed to percolate through the weathered rock (pH 5), and radionuclide migration was retarded by reactions with the fill and soil. More than 1 million Ci of fission products (approximately 75% ^{137}Cs and 25% ^{90}Sr) with some activation products, actinides, and transuranics were disposed in this manner before the implementation of hydrofracture. Migration of ^{106}Ru was reported from the beginning of the operation of seepage pits 1, 2, and 3, and in 1959 the pits became overloaded and large releases of ^{106}Ru occurred (Cowser 1963). LLW trench 7 has also been suspect because of the occurrence of a nearby alkaline seep (pH of about 8), which contains relatively high concentrations of ^{3}H, ^{99}Tc, ^{60}Co, ^{233}U, ^{244}Cm, ^{241}Am, and ^{238}Pu. Seeps also occur in the vicinity of the other formerly used pits and trenches; all the seeps are upgradient from WOC and its tributaries. Thus the pits and trenches have been a significant source of contaminants to the flow system.

There are a number of ponds that have contained contaminated liquids in the past or are currently used for waste-holding or processing applications. The Equalization Basin (Site 3524), 190 Ponds (Sites 3539 and 3540), the 3513 Pond, and the East Sewage Plant Lagoon are situated on the south side of the main ORNL complex between White Oak Avenue and WOC. The Equalization Basin and 190 Ponds, as active parts of the ORNL radioactive waste management system are being used for holdup of process liquid waste before its treatment in the Process Waste Treatment Plant (Building 3544) or discharge to WOC. Five ponds are located in Melton Valley, four in the High-Flux Isotope Reactor (HFIR)/TRU complex, and one in SWSA 5. The four ponds in the HFIR/TRU complex (Sites 7905, 7906, 7907, and 7908) serve as process liquid waste collection and sampling basins. The HFIR ponds (7905 and 7906) also collect cooling tower blowdown. These basins are sampled regularly and discharged to the Process Waste Treatment Plant or WOC watershed, depending upon activity levels present.

A.2 GEOLOGY AND SOILS

The Oak Ridge Reservation lies in the Ridge and Valley Province (Fenneman 1938), which is characterized by multiple, northeasterly trending, elongate valleys separated by ridges that locally are 61 m (200 ft) to 152 m (500 ft) high. In the vicinity of the Laboratory, the succession of alternating ridges and valleys from the Clinch River to the northwest is Copper Ridge, Melton Valley, Haw Ridge, Bethel Valley, and Chestnut Ridge (Fig. 1).

Four major geologic units underlie the WOC drainage basin from northwest to southeast, the Knox Group of Cambrian and Ordovician age, the Chickamauga Limestone of Ordovician age, and the Rome Formation and the Conasauga Group of Cambrian age.

As is discussed in Webster (1976), the Knox group underlies much of Chestnut and Copper Ridges, which bound the drainage basin to the north and south. The group is composed largely of cherty dolomite in which sinkholes and caverns have developed. The Knox is considered an unsuitable unit for the disposal of waste because the avenues by which water moves in cavernous rock, particularly at depth, are unknown, unpredictable, and virtually unmonitorable. Nevertheless, the Knox is beneficial to waste disposal at the Laboratory; its reservoir of water discharges to the WOC drainage and thus dilutes the concentrations of contaminants discharged to the creek.

The Chickamauga Limestone underlies Bethel Valley, much of the Laboratory area, and SWSAs 1, 2, and 3 near WOC (Fig. 2). It is composed predominantly of limestone, although shales, siltstones, and bedded chert comprise a significant minor part of the formation. The strata generally are thin- to medium-bedded. Fractures and solution openings occur between the beds of the Chickamauga, but the rock is believed free of large openings such as those found in the Knox. Nevertheless, the presence of cavities, even though of smaller dimensions, presents the same problems regarding deep groundwater movement and radionuclide monitoring.

The Rome Formation in the WOC basin is exposed along Haw Ridge. Locally, the bulk of the formation consists of soft, argillaceous shale containing occasional thin, siltstone layers less than 1 in. thick. The Rome is considered unsuitable for trench-type disposal because of its exposure along moderately steep slopes, shallow depth of soil weathering, and difficulty of excavation (Webster 1976).

The Conasauga Group, commonly referred to as the Conasauga shale, underlies Melton Valley, including SWSAs 4, 5, and 6, and the pits and trenches formerly used for liquid waste disposal (Fig. 2). The lithologic character of the rock is variable, both along strike and in superposition. The general sequence through the formation is gradational, from shale at its base to bedded limestone at its top. In the waste disposal areas, the unit contains many interbeds of shale, siltstone, and limestone. Much of the carbonate within the weathered zone of the interbedded strata has been removed by leaching. In general, the weathered limestone layers have been reduced to silty clay and the shale layers to a fine, silty sand (DeLaguna et al. 1958). WOL and the lower part of WOC rest on limestone or shaly limestone of the Conasauga Group (Barnett 1954).

All the formations in the drainage basin strike northeast at about 56° and dip southeast at angles commonly between 30 and 40°. The major structural feature in the area is the Copper Creek thrust fault, which appears on the northwest flank of Haw Ridge and extends across the entire width of Tennessee. Millions of years ago the Rome and overlying formations in the basin were displaced northwesterly over the younger Chickamauga Limestone for a distance of about 2195 m (7200 ft), and the originally flat-lying beds in the region were deformed into multiple northeast-trending folds. The shales, siltstones, and thin limestones of the Conasauga, and particularly the thin-bedded, less silty shales of that unit, were highly deformed, and many small structures and variations of strike and dip were imparted. Small anticlines and synclines are common; in places they have smaller folds on their flanks and are cut by a number of steeply dipping faults of small displacement. Excavation of pit 4 near WOL showed that beds in that locale are intensely and irregularly folded and crumpled.

The soils of the Laboratory area are characterized by being strongly leached and low in organic matter. The soils are further characterized as silty, although considerable amounts of clay may be present, and acidic in reaction, with a pH from about 4.5 to 5.7 (Carroll 1961).

The clay component of the soils commonly consists of a mixture of several clay minerals. The principal clay mineral developed by weathering of the dolomite of the Knox Group is kaolinite. The Chickamauga weathers to form a mixture of kaolinite and illite, and some units of that formation have significant amounts of montmorillonite. The Rome decomposes to provide only a small amount of unidentified clay, and the Conasauga, where the largest burial grounds are located, decays to form illite and vermiculite (McMaster and Waller 1965).

Physically, the clays are a mass of very small particles that collectively have a very large total surface area. Because of this property, the clays may have a large capacity to remove ions, including radioactive ions, from solution by processes termed sorption and ion exchange, provided that the fluid has intimate contact with the individual particles of clay -- that is, if the fluid can move between the grains rather than through some small portion of the mass -- and if other controlling factors allow. The sorptive properties of each of the clay minerals vary for specific radionuclides.

A.3 HYDROLOGY

Flow has been monitored in the White Oak watershed since the early 1950s. Early discharge data collected by the U.S. Geological Survey at three sites in the watershed (Fig. 2) [WOD (Station 5), WOC 0.16 km (0.1 mile) above Melton Branch (Station 3), and Melton Branch 0.16 km (0.1 mile) above WOC (Station 4)] are shown in Table A.1. Flow-duration curves for mean daily flow at WOD for 1953-55 and 1960-63 presented by McMaster (1967) indicated that flow during these 5 years equaled or exceeded 4.2 m^3/s (150 ft^3/s), the maximum measurable flow, only 0.15% of the time or 0.5 d/year. The average number of days when flow exceeded 4.2 m^3/s during 1972-79 was 5.25 d/year (Oakes et al. 1982). Representative discharge values and corresponding flow duration from a McMaster (1967) analysis are shown in Table A.2.

Edgar (1978) analyzed the results of various investigators' estimates of flood discharge by using precipitation records and equations based on the drainage area and precipitation. The results of a frequency analysis by Sheppard (1974) of annual maximum precipitation for varying durations for 1951-74 at the Oak Ridge Townsite station are given in Fig. A.1 and Table A.3 (Oakes et al. 1982). Table A.3 shows

Table A.1. Discharge data for White Oak Creek and Melton Branch

Station	Discharge[a] (ft3/s) Average	Minimum	Maximum	Period of record (years)
White Oak Creek 0.1 mile above Melton Branch	9.62	1.9	642	10 (1950-52, 1955-63)
Melton Branch 0.1 mile above White Oak Creek	2.50	no flow	242	8 (1955-63)
White Oak Dam	13.5	no flow	669	5 (1953-55, 1960-63)

[a]Note: multiplying ft^3/s by 2.83×10^{-2} will convert ft^3/s to m^3/s.

Source: Webster 1976.

Table A.2. Daily flow duration values for White Oak Creek at White Oak Dam (1953-55, 1960-63)

Flow [m^3/s (ft^3/s)]		Percentage of time indicated discharge was equaled or exceeded
0.048	(1.7)	99.9
0.054	(1.9)	99
0.093	(3.3)	90
0.125	(4.4)	80
0.150	(5.3)	70
0.178	(6.3)	60
0.207	(7.3)	50
0.246	(8.7)	40
0.311	(11.0)	30
0.425	(15.0)	20
0.651	(23.0)	10
2.83	(100.0)	1
7.08	(250.0)	0.1

Source: McMaster 1967.

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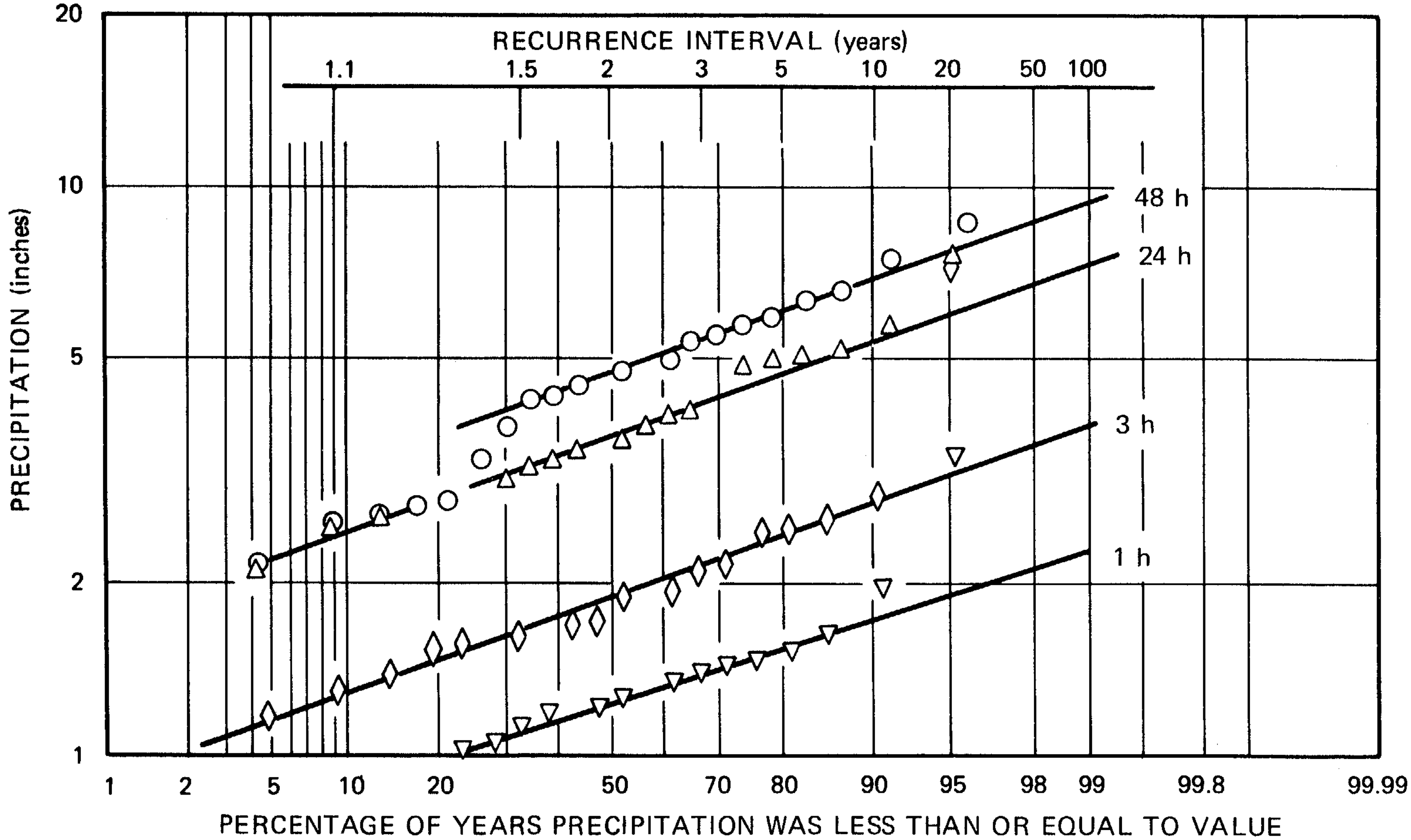

Fig. A.1. Frequency of maximum annual precipitation at Oak Ridge for 1-, 3-, 24-, and 48-h storms. Note: multiplying inches by 25.4 will convert inches to millimeters. Source: Oakes et al. (1982).

Table A.3. Estimates of flood discharge of various recurrence intervals computed by the method proposed by Sheppard,[a] White Oak Creek at White Oak Dam

(Discharge measured in cubic feet per second)

Recurrence interval (year)	Precipitation duration (h)			
	1	3	24	48
1.1		33	123	202
2	28	71	255	435
5	44	87	435	709
10	57	155	575	911
25	79	202	733	1200
50	95	241	885	1458
100	104	285	1022	1704

[a]J. D. Sheppard (1974).

Source: D. E. Edgar (1978).

flood discharge calculated by Edgar using a method proposed by Sheppard and the precipitation data from Fig. A.1. Flood discharge estimates calculated from a set of equations presented by Randolph and Gamble (1976) to estimate flood magnitude of selected frequency in Tennessee were very similar to those calculated by Edgar. Flood frequencies calculated for monitoring stations 3 (WOC), 4 (Melton Branch), and 5 (WOD) are shown in Fig. A.2. Discharge data for WOD from four major storms are given in Table A.4. These storms resulted in stream discharges that exceeded measurement capacity at WOD for varying periods of time.

As part of a project to upgrade the Melton Branch, WOC, and WOD stream monitoring stations, new weirs, equipment shelters, and monitoring and sampling equipment were installed in late 1983. The flow at the weirs is measured with an ultrasonic flow meter that contains a microprocessor to translate weir water level to a flow proportional control for the water sampler. At each of the stations, equipment was installed to provide water sampling proportional to stream flow. To establish radiation levels of the water effluent, new gross beta and gamma radiation monitoring equipment was installed. In addition, a robot monitor was used to monitor the following parameters continuously: pH, dissolved oxygen, turbidity, conductivity, and temperature. The robot monitor is a modular, automatic water quality data acquisition system capable of meeting National Pollutant Discharge Elimination System requirements. A microprocessor is provided at each station to monitor the data and alarm signals, which are then telemetered to the waste operations control center (Martin Marietta Energy Systems, Inc. 1985).

Flow at the three monitoring stations and precipitation in the watershed for 1985 are shown in Fig. A.3. As compared to long-term precipitation data for the Oak Ridge area (Fig. 5), 1985 precipitation was below average most of the year and stream flow was correspondingly low. During extended periods of little or no precipitation, groundwater inflow and Laboratory effluent, both of which may be contaminated, make up most of the flow in WOC. For Melton Branch, most of the baseflow is cooling water from the HFIR.

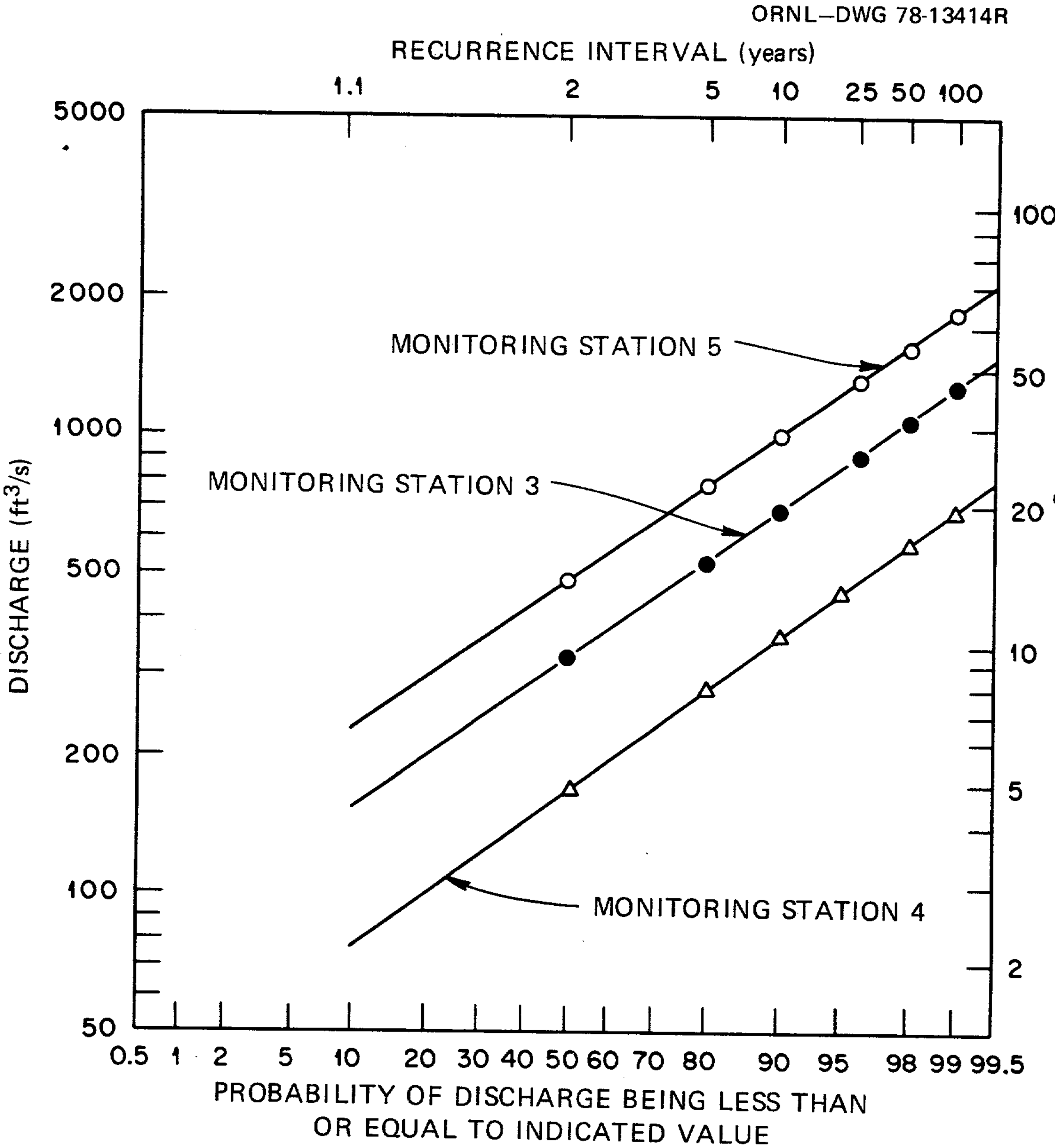

Fig. A.2. Flood frequency curves for monitoring stations 3, 4, and 5. Source: Oakes et al. (1982).

Table A.4. Data at White Oak Dam for four floods

Date	Precipitation		Estimated	Estimated
	Total [cm (in.)]	Duration (h)	peak discharge [m^3/s (ft^3/s)]	recurrence interval (years)
Mar. 15-16, 1973	17.3 (6.8)	48	25.8 (910)	5.7
Nov. 27-28, 1973	22.1 (8.7)	48	42.2 (1492)	25
Apr. 2-4, 1977	14.7 (5.8)	41	18.7 (660)	2.3
June 7-8, 1978	9.6 (3.8)	48	8.07 (285)	1-1.5

Sources: Oakes et al. (1982); Sheppard (1974); Edgar (1978).

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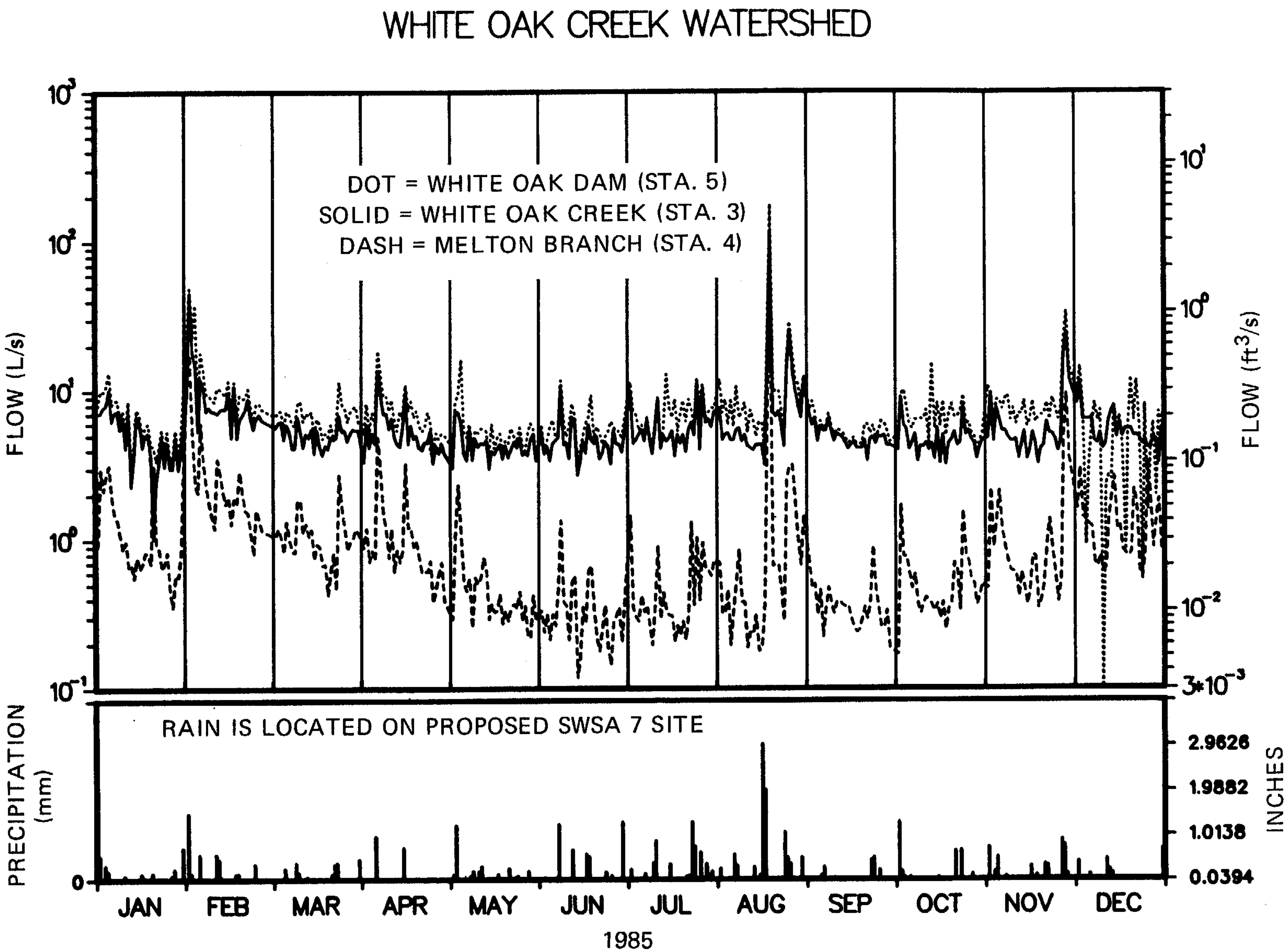


Fig. A.3. Flow and precipitation in the White Oak Creek watershed in 1985.

A description of sampling sites for ecological studies during March 1979 through February 1980 provides an indication of the nature of the physical dimensions and substrate in different reaches of WOC and Melton Branch (Loar et al. 1981a). Sampling sites on Melton Branch and WOC near the headwaters were located on reaches of similar width (2.7 to 3 m) and depth (11 cm). The substrate at both sites consisted primarily of medium (fist-size) to small rubble, with some gravel and sand. Areas of embedded rubble and exposed bedrock were also characteristic of the two areas. Below ORNL, WOC is wider and deeper, and the substrate consists almost entirely of small rubble and gravel. The stream near all four sampling locations consists of alternating series of pool and riffle areas.

A.3.1 White Oak Lake

WOL is a small, shallow impoundment that functions as a final settling basin for waste effluents discharged to the lake via WOC, Melton Branch, and other smaller streams. As is summarized in Loar et al. (1981), the lake has undergone several significant changes since its impoundment in 1943 (Table A.5). The water level was lowered in 1953 during the fish population studies of Krumholz (1954a,b,c), and in 1955 the lake was drained and the surface area reduced to 2.8 ha (Kolehmainen and Nelson 1969). From 1955 to 1963, thick grasses, herbs, and shrubs covered the former lake bottom (Kolehmainen and Nelson 1969). The size of WOL varied somewhat over the next 15 years until late November 1979, when the lake level was gradually lowered from 227.1 m (745 ft) MSL to 226.2 m (742 ft) MSL (Oakes et al. 1982), resulting in an estimated reduction in surface area of about 5.2 ha.

In addition to the changes that resulted whenever the lake was drained (or partially drained), the accumulation of sediment over the years has altered the environment of WOL. The average annual rate of sediment accumulation before 1953 was estimated to be 2832 m^3 (100,000 ft^3), or about 2 cm/year (Loar et al. 1981), based on a lake surface elevation of 228.0 m (748 ft), a surface area of 14.5 ha (35.87 acres) (Krumholz 1945a), and a lake volume of 171,324 m^3 (6,049,587 ft^3) in June 1953 (Morton 1963).

Table A.5. Historical changes in the surface area of White Oak Lake and the major events associated with significant changes in lake size

Date	Surface area (ha)	Event	Reference
1941		Highway fill raised and concrete culvert installed	Smith (1945) as cited in Krumholz (1954a)
1943	14.5[a]	Vertical sliding gate [top elevation = 228.6 m (750 ft) MSL] installed and spillway closed in October	Krumholz (1954a)
		Generation of radioactive liquid waste at ORNL began and lake served as final settling basin	Clinch River Study Steering Committee (1967)
1945	~12.2	Investigation of structural strength of dam under flood conditions; lake level maintained at 227.5 m (746.5 ft) until June 1948	Oakes et al. 1982
June 1948	~10.3	Lake level lowered to 227.2 m (745.3 ft) to facilitate mud sampling. Normal operation from 1948 to 1955 was between elevations 227.7 m (747 ft) and 228.3 m (749 ft)	Oakes et al. 1982
April 1953	N/A	Lake partially drained during rotenone survey of fish populations	Krumholz (1954c)
October 1955	2.8[b]	Lake drained; accumulation of radionuclides in lake sediments had come into equilibrium with radioactivity in water, so lake served no useful function in retaining radioactivity but could function as an emergency storage pond in case of accidental release	Clinch River Study Steering Committee (1967)
Summer 1956	0.4	None reported[c]	Lackey (1957)
1959	N/A	Gate structure renovated to prevent inflow of backwaters from Clinch River	Clinch River Study Steering Committee (1967)
1960	3.2	Dam closed; surface level raised 7.6 cm (3 in.)	Kolehmainen and Nelson (1969)
May 1963	6.0	Completion of Melton Hill Dam	Kolehmainen and Nelson (1969)
1967	8.1[d]	None reported	McMaster (1967)
1969	10.5	None reported	Kolehmainen and Nelson (1969)
November 1979	4.6	Lake level gradually dropped from 227.1 to 226.2 m (745 to 742 ft) MSL due to potential leakage and instability of the dam. Construction of a berm to stabilize the dam was completed in March 1980.	Oakes et al. 1982

[a]At normal pool elevation of 228.0 m (748 ft) mean sea level (MSL); at full pool (228.6 m or 750 ft MSL), the surface area is 17.9 ha (Krumholz 1954a).

[b]Kolehmainen and Nelson (1969).

[c]According to Lackey (1957, p. 15), ". . . in the summer of 1956 the main body of the lake had been drained, leaving a small pool of about one acre [0.4 ha] above the White Oak Dam."

[d]Same surface area was reported by Dahlman, Kitchings, and Elwood (1977) and Edgar (1978).

Source: Loar et al. 1981.

Oakes et al. (1982) presents extensive compilations relating lake elevations to area, volume, and depth. The lake area vs elevation is given in Table A.6. The estimated depth of WOL at elevation 227 m for 1953-79 is given in Table A.7.

A.3.2 Chemical Quality

The effects of plant operations on water quality in the creek and lake have been studied since the early 1940s. At WOD the water reflects the many man-made influences on the creek and tributaries in Bethel and Melton Valleys, as well as the beneficial effects of WOL.

The annual discharge of radionuclides to the Clinch River through WOD from 1949-80 is given in Table A.8. The calculated concentration of radionuclides released may be compared to representative maximum permissible concentrations (MPC), which are based on dose standards for individuals exposed to radiocontaminants in drinking water (DOE Manual Chapter 0524, Standards for Radiation Protection). The percentage of MPC at WOD from 1974-80 is given in Fig. A.4. Oakes et al. (1982) indicated that approximately 70% of the MPC values are due to ^{90}Sr, 20% to ^{3}H, and the remainder to transuranics and other isotopes.

An intensive sampling program was conducted at WOD during a period of declining water levels in November and December of 1979 to secure detailed water quality data. Samples were collected hourly for several days beginning November 20 and then at 8-h intervals until December 28. The range of values for selected radionuclides is given in Table A.9.

Several studies have been conducted to determine the effects of flow variations in WOC on concentrations of radionuclides into water and sediment. Studies in 1962 (Lomenick et al. 1963), which included flow rates of 140 l/s (5 ft^3/s) to 1600 l/s (57 ft^3/s) and suspended solids variations from 0.004 to 3.26 g/l indicated that (1) during quiescent periods with low flow and low suspended solids, ^{137}Cs was found mainly in the liquid phase, with smaller quantities in the sediment, whereas at higher flows caused by light rainfall (Fig. A.5) the ^{137}Cs increased with stream flow (and suspended solids concentrations) while ^{137}Cs in solution showed little change; and

Table A.6. White Oak Lake area vs elevation

Elevation [m (ft)]	Area [ha[a] (acres)]
228.6 (750)	17.7 (44.19)
228.3 (749)	16.0 (39.90)
228.0 (748)	14.3 (35.67)
227.7 (747)	12.9 (32.29)
227.4 (746)	11.4 (28.57)
227.1 (745)	9.8 (24.48)
226.7 (744)	7.6 (19.11)
226.5 (743)	5.8 (14.43)
226.2 (742)	4.6 (11.45)
225.9 (741)	2.8 (7.07)
225.6 (740)	1.6 (3.88)
225.2 (739)	0.67 (1.67)
224.9 (738)	0.24 (0.60)
224.6 (737)	0.08 (0.21)
224.3 (736)	0.04 (0.09)
224.0 (735)	0.02 (0.04)
223.8 (734.1)	0.00 (0.00)

[a] 1 ha = 10,000 m^2.

Source: Oakes et al. 1982.

Table A.7. Estimated maximum depth of White Oak Lake at elevation 227 m (745 ft) vs year, 1953-1979

Year	Lake depth [m (ft)]	Year	Lake depth [m (ft)]
1953	3.05 (10)	1967	2.75 (9.02)
1954	3.03 (9.93)	1968	2.73 (8.95)
1955	3.01 (9.86)	1969	2.71 (8.88)
1956	2.98 (9.79)	1970	2.69 (8.81)
1957	2.96 (9.72)	1971	2.66 (8.74)
1958	2.94 (9.65)	1972	2.64 (8.67)
1959	2.92 (9.58)	1973	2.62 (8.6)
1960	2.90 (9.51)	1974	2.60 (8.53)
1961	2.88 (9.44)	1975	2.58 (8.46)
1962	2.86 (9.37)	1976	2.56 (8.39)
1963	2.83 (9.44)	1977	2.54 (8.32)
1964	2.81 (9.23)	1978	2.51 (8.25)
1965	2.79 (9.16)	1979	2.49 (8.18)
1966	2.77 (9.09)		

Source: Oakes et al. 1982.

Table A.8. Annual discharges of radionuclides to the Clinch River, 1949 to 1980
(Measurements are in Curies)

Year	^{137}Cs	^{106}Ru	^{89}Sr	^{90}Sr	TRE*(-Ce)[a]	^{144}Ce	^{95}Zr	^{95}Nb	^{131}I	^{60}Co	^{3}H	TRU
1949	77	110		150	77	18	180	22	77		NA[b]	0.009 (from 8/12/49)
1950	19	23		38	30	NA	15	42	19			0.04
1951	20	18		29	11	NA	5	2	18			0.08
1952	10	15		72	26	23	19	18	20			0.03
1953	6	26		130	110	7	8	4	2			0.08
1954	22	11		140	160	24	14	9	4	NA		0.07
1955	63	31		93	150	85	5	6	7	7		0.25
1956	170	29		100	140	59	12	15	4	46		0.28
1957	89	60		83	110	13	23	7	1	5		0.15
1958	55	42	NA	150	240	30	6	6	8	9		0.08
1959	76	520	0.3	60	94	48	27	30	1	77		0.68
1960	31	1900	1.9	28	48	27	38	45	5	72		0.19
1961	15	2000	2.0	22	24	4	20	70	4	31		0.07
1962	6	1400	1.7	9	11	1	2	8	0.4	14		0.06
1963	4	430	1.0	8	9	2	0.3	0.7	0.4	14		0.17
1964	6	191	0.8	7	13	0.3	0.2	0.1	0.3	15	1,929	0.08
1965	2	69	0.6	3	6	0.1	0.3	0.3	0.2	12	1,161	0.50
1966	2	29	0.9	3	5	0.1	0.7	0.7	0.2	7	3,090	0.16
1967	3	17	0.7	5	9	0.2	0.5	0.5	0.9	3	13,273	1.03
1968	1	5	0.6	3	4	0.03	0.3	0.3	0.3	1	9,685	0.04
1969	1	2	0.3	3	5	0.02	0.2	0.2	0.5	1	12,247	0.20
1970	2	1	0.3	4	5	0.06	0.02	0.02	0.3	1	9,473	0.40
1971	1	0.5	0.2	3	3	0.05	0.01	0.01	0.2	1	8,945	0.05
1972	2	0.5	NA	6	5	0.03	0.01	0.01	0.3	1	10,600	0.07
1973	2	0.7		7	NA	0.02	0.05	0.05	0.5	1	15,000	0.08
1974	1	0.2		6		0.02	0.02	0.02	0.2	0.6	8,611	0.02
1975	0.6	0.3		7		NA	NA	NA	0.3	0.5	11,001	0.02
1976	0.2	0.2		5					0.03	0.9	7,422	0.01
1977	0.2	0.2		3					0.03	0.4	6,249	0.03
1978	0.3	0.2		2					0.04	0.4	6,292	0.03
1979	0.2	0.1							0.04	0.4	7,700	0.03
1980	0.6	0							0.04	0.4	4,554	0.04

[a]Total rare earths minus cerium.
[b]No analysis performed.

Source: Oakes et al. 1982.

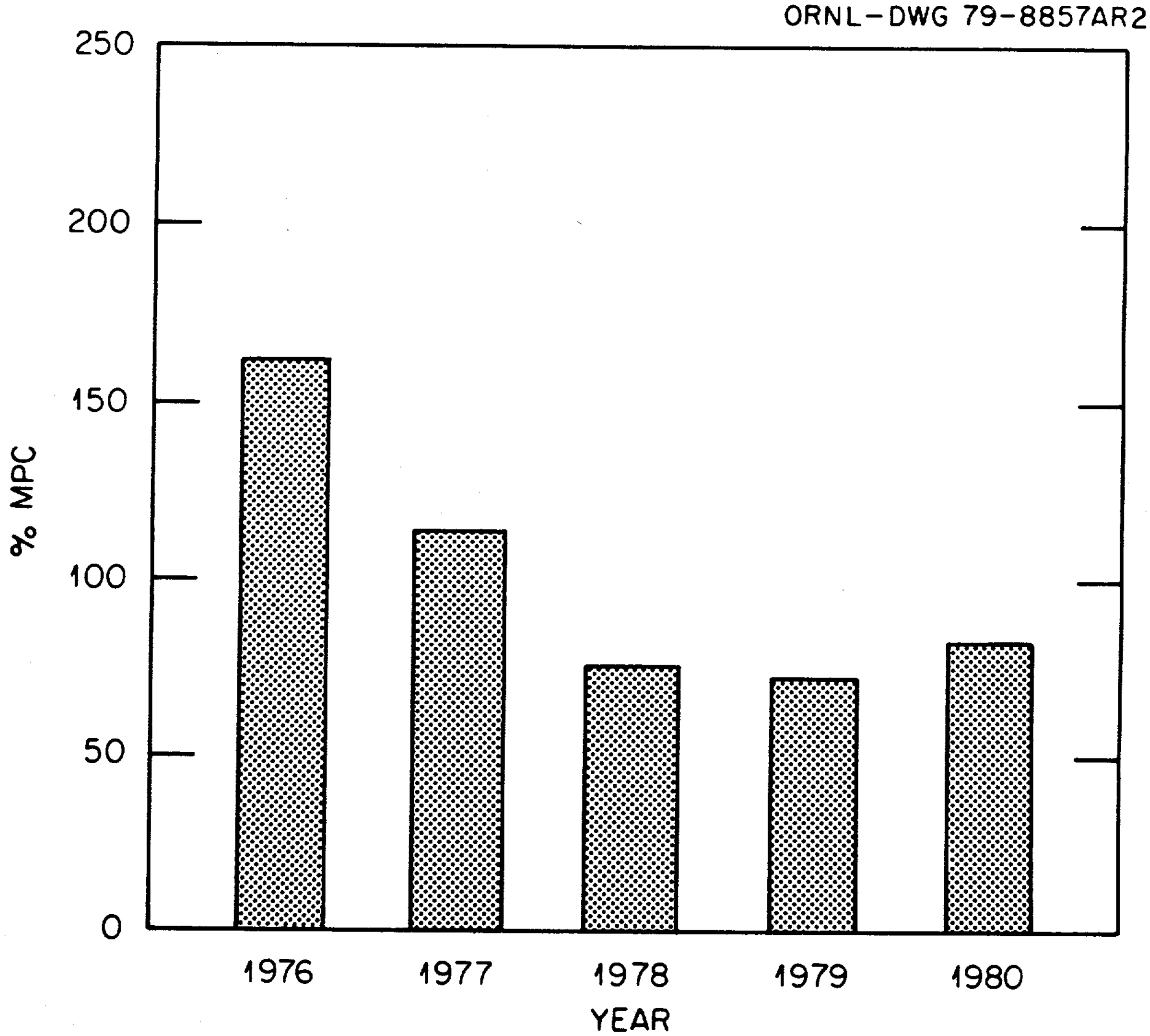


Fig. A.4. Percent of MPC total over WOD. Source: Oakes et al. (1982).

Table A.9. Water data for White Oak Dam November-December 1979 [Bq/ℓ (pCi/l)]

[Measurements are in becquerels per liter (picocuries per liter)]

Radionuclide	Minimum	Maximum	MPC_w
^{137}CS	0.6 (15)	8.0 (215)	740 (20,000)
^{60}Co	1.8 (49)	12.6 (340)	1,850 (50,000)
^{90}Sr	15 (405)	22.2 (600)	11.1 (300)
Gross α	1.0 (27)	11.5 (310)	
Gross β	81.4 (2,200)	215 (5,800)	
^{3}H	17,390 (470,000)	26,640 (720,000)	111,000 (3,000,000)

Source: Oakes et al. 1982.

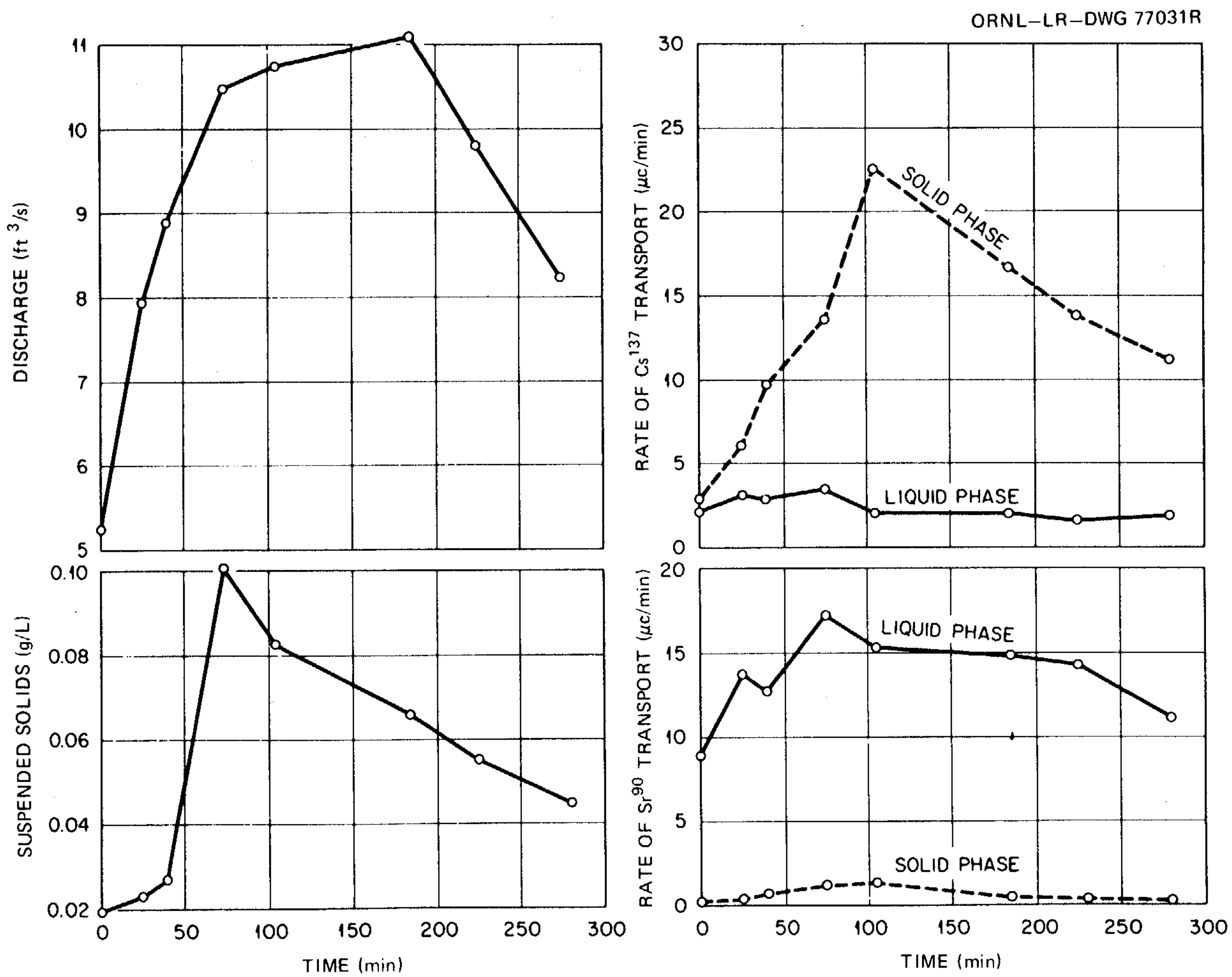


Fig. A.5. Stream flow, concentration of suspended solids, and ^{90}Sr and ^{137}Cs transport in White Oak Creek resulting from light rainfall, adapted from Lomenick et al. (1963). Source: Oakes et al. (1982).

(2) most (>95%) of the ^{90}Sr occurred in the liquid phase, which increased with flow while the ^{90}Sr in sediment showed little change with increasing stream flow.

Oakes et al. (1982) reported on two studies of high flow conducted during periods of heavy rainfall, March 4-5 and June 3-4, 1979. Figure A.6 shows the flow pattern during the March 4-5 study, starting with a flow of 1400 l/s, reaching a peak of 8000 l/s after 5 or 6 h, then tapering off to a flow of 1400 l/s on March 5. Figure A.7 shows the highly similar pattern of the sediment transfer for the same period. During the peak flow period, sediment was moving across the dam at 0.8 to 0.9 kg/s. Figures A.8 and A.9 show the temporal variation of radionuclide in sediment and in solution-both of which follow patterns similar to those of the flow. The sediment radioactivity consists predominately of ^{137}Cs, with lesser quantities of ^{60}Co and ^{90}Sr. The ^{137}Cs transport in solids peaked at approximately 300 kBq/s (8 µCi/s), near the flow maximum. However, the ^{137}Cs content per gram of sediment was greatest near the beginning of the experiment when the sediment levels were on the order of 10 to 12 mg/l. As shown in Fig. A.9, ^{90}Sr and ^{60}Co are the two major nuclides moving in solution across the dam. Cesium-137 was not detected in solution after the first 4 h.

On the basis of results from the studies of March 3 and 4, it can be shown that ^{137}Cs movement out of the WOC-WOL system is almost exclusively as a component of sediment, whereas ^{90}Sr moves mainly in solution. Movement of ^{60}Co is intermediate between the other nuclides, moving in both solution and sediment phases (Oakes et al. 1982). This agrees with past data that showed 2% of ^{90}Sr moved with the sediment, 6% for ^{106}Ru, 19% for ^{60}Co, and 69% for ^{137}Cs (Struxness et al. 1967).

A second high-flow study was performed during heavy rains and high-flow-rate conditions during a 1-d storm on June 3-4, 1979, which produced flows of more than 10,000 l/s and suspended solids transport of 0.6 to 0.7 kg/s. The data presented for the second high-flow study were very similar to those of the first study and the conclusions were

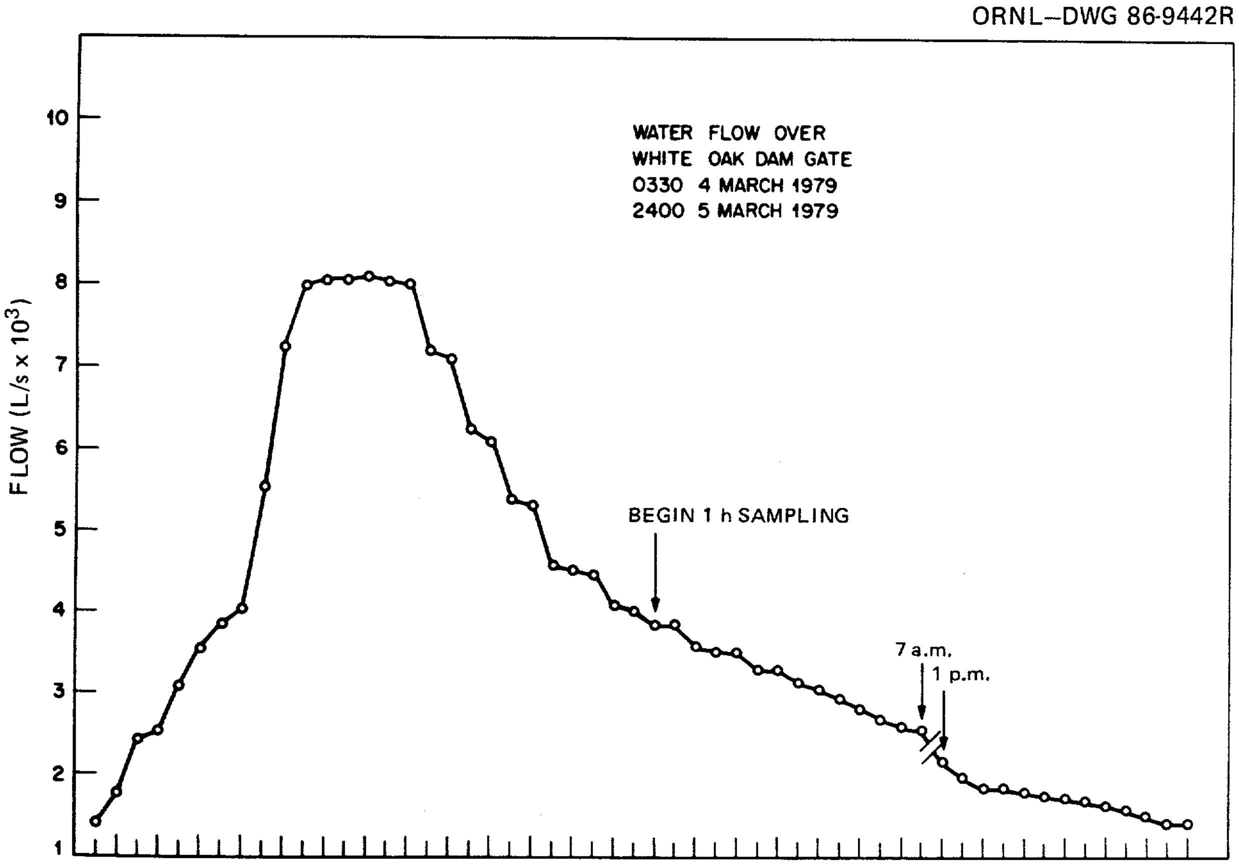


Fig. A.6. Water flow profile over WOD, 0330 March 4 to 2400 March 5, 1979. Source: Oakes et al. (1982).

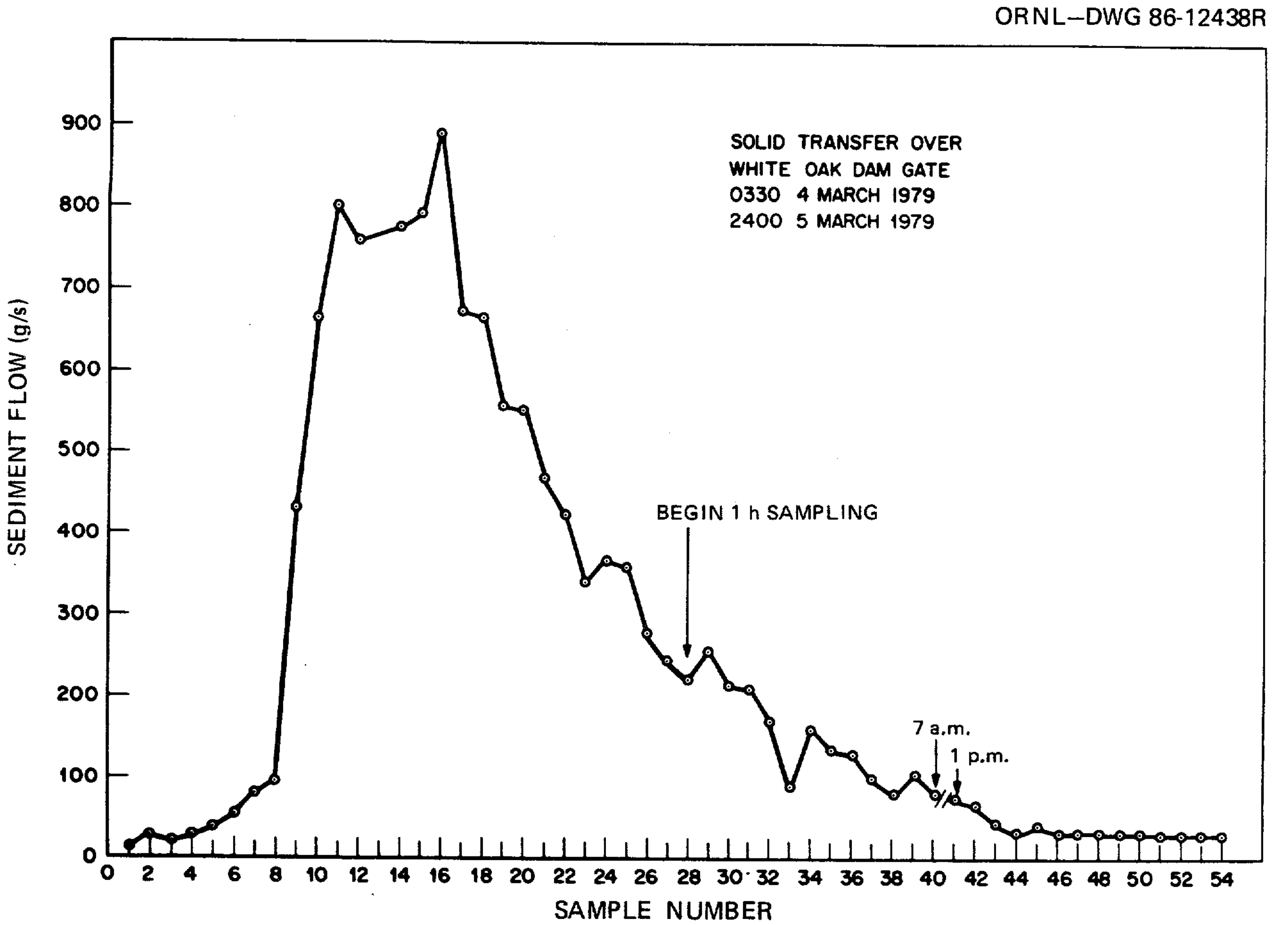


Fig. A.7. Sediment transfer over White Oak Dam, 0330 March 4 to 2400 March 5, 1979. Source: Oakes et al. (1982).

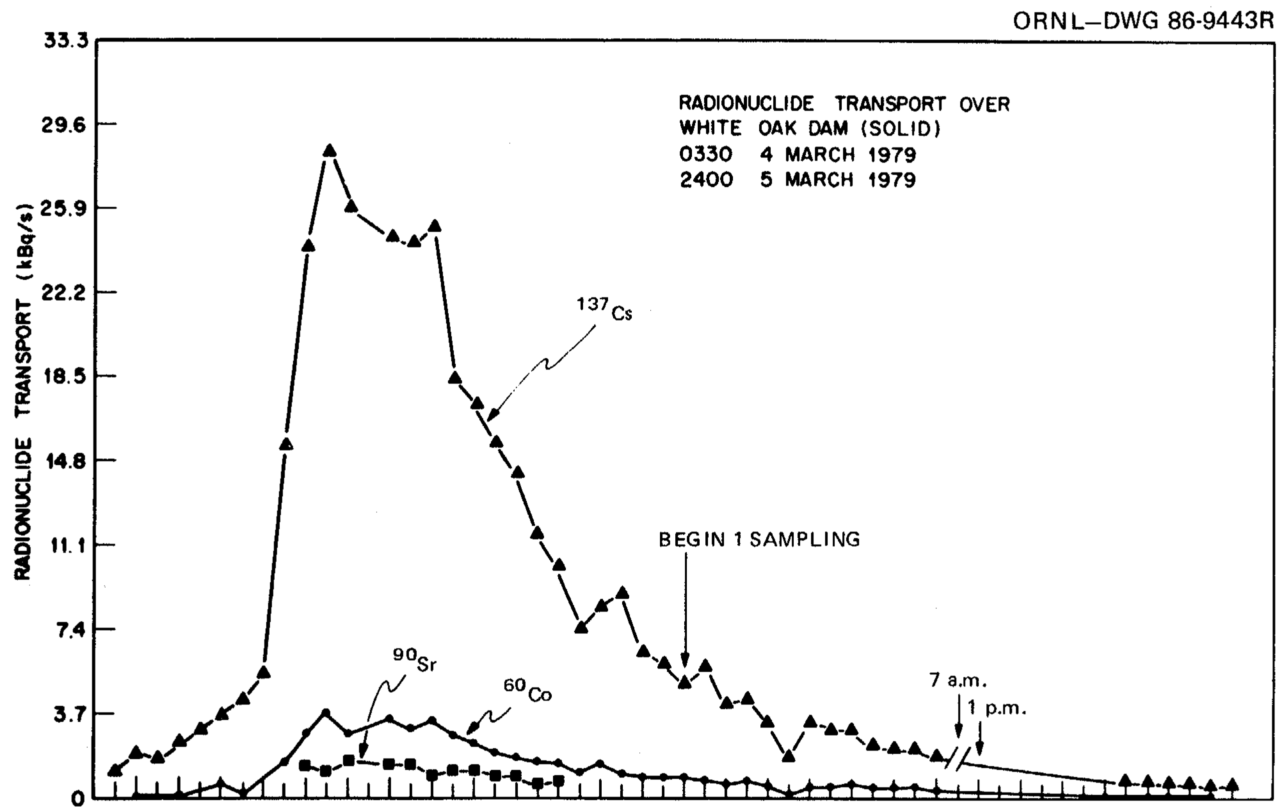


Fig. A.8. Temporal variation of radionuclide transport in sediments over White Oak Dam, 0330 March 4 to 2400 March 5, 1979. Source: Oakes et al. (1982).

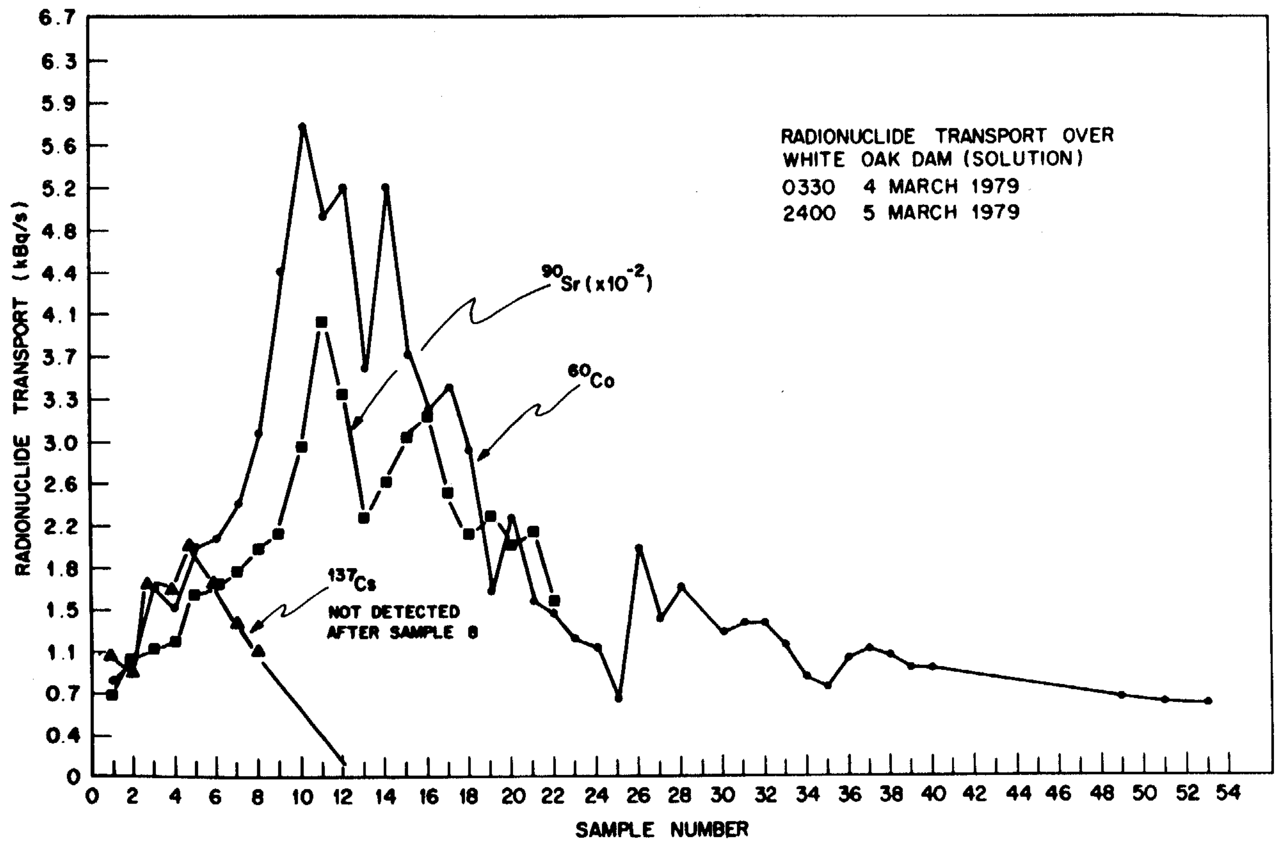


Fig. A.9. Temporal variation of radionuclide transport in solution over White Oak Dam, 0330 March 4 to 2400 March 5, 1979. Source: Oakes et al. (1982).

the same: the major transport mechanism for ^{137}Cs out of the WOL system is as a component of sediment during high-flow conditions. Strontium-90 moves mainly in solution, while ^{60}Co behaves intermediately (Oakes et al. 1982).

Sediment transport as a function of flow can be used to calculate the total annual sediment discharge. Lomenick et al (1963) noted a variation in sediment concentrations of 4 mg/l at 0.14 m^3/s (4.99 ft^3/s) to 44 mg/l at 1.6 m^3/s (57 ft^3/s). Normal concentrations are approximately 10 to 12 mg/l. For 10 mg/l, a sediment density of 1.1 g/cm^3, and a discharge of 1.1×10^6 m^3/month (average flow over WOD for 1978), a total amount of 120 m^3/year is calculated to have been discharged. The average concentration during December 1979, when the lake was draining, was 60 mg/l; this results in a yearly amount of 720 m^3/year. Measurements made on sediment discharge when the lake was completely drained in the late 1950s resulted in an average of 4200 m^3/year (Lomenick et al. 1961).

A.3.3 <u>Radioactivity in sediments</u>

Radioactivity in sediments in WOC and WOL has been studied since the mid-1940s. Studies conducted from 1945 to 1979 are summarized from a historical review by Oakes et al. (1982).

In 1945 and 1946, samples were collected in five sections of the lower WOC drainage system (Fig. A.10); the marsh, intermediate pond, WOL mud flats, WOL, and WOC downstream from the dam (Cheka and Morgan 1947). Total and average radioactivity in the section during 1945-46 are shown in Table A.10

Sediment samples were collected at 30-m (100-ft) intervals on WOL bed during 1950-52 (Abee 1953). Total and average activity in the lake bed determined from this sampling and from samples collected during 1948-49 are given in Table A.11. The lake was lowered during fish population studies in 1953 (Krumholz 1954c) and drained to a surface area of 2.8 ha in 1955 (Kolehmainen and Nelson 1969).

The results of strontium analysis of 68 soil samples collected during 1956-58 (Auerbach et al. 1959) indicate that ^{90}Sr levels in

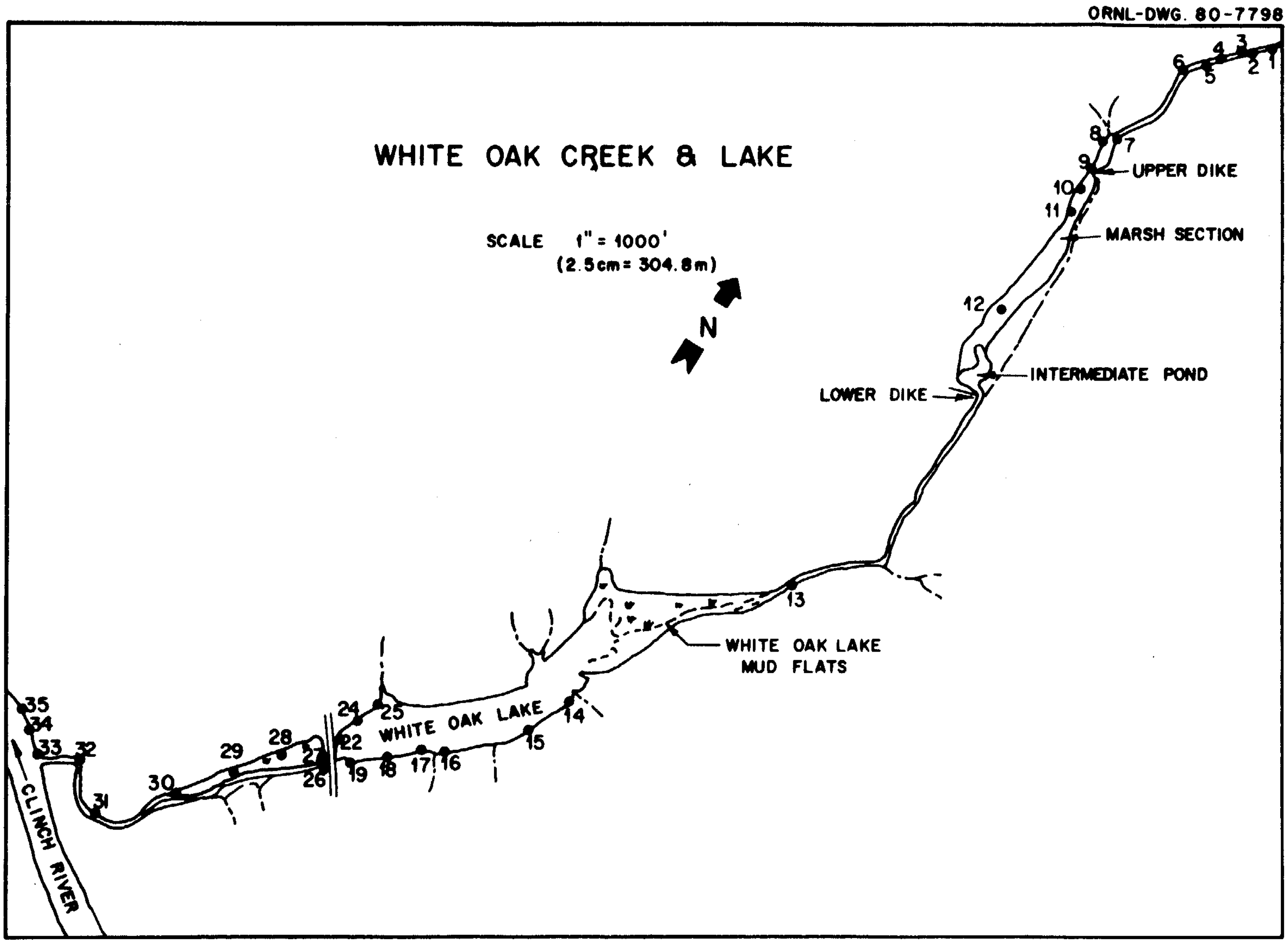


Fig. A.10. Sediment sampling locations during 1945 and 1946, adapted from Chela and Morgan (1947). Source: Oakes et al. (1982).

Table A.10. Total activity of White Oak drainage system, 1945–46

Location	Distance below settling pond	1945			1946		
		Average		Total	Average		Total
	[m (ft)]	[MBq/m^2	(μCi/ft^2)]	[TBq (Ci)]	[MBq/m^2	(μCi/ft^2)]	[TBq (Ci)]
Marsh	646 (2,120)	36.4	(91.5)	1.58 (42.7)	58.0	(145.5)	2.51 (67.8)
Intermediate pond	991 (3,250)	34.9	(87.6)	0.17 (4.6)			
White Oak Lake mud flats	2103 (6,900)	8.8	(22.0)	0.55 (14.9)	3.8	(9.6)	0.24 (6.5)
White Oak Lake	2621 (8,600)	3.4	(8.5)	0.25 (6.8)	6.8	(17.1)	0.5 (13.6)
Area below spillway	3155 (10,350)	0.41	(1.04)	0.01 (0.3)	1.1	(2.7)	0.03 (0.9)
Total				2.56 (69.3)			3.28 (88.8)

Source: Cheka and Morgan 1947.

Table A.11. Total activity in White Oak Lake, 1948-52

Year	Total activity [TBq	(Ci)]	Average [MBq/m^2	($\mu Ci/ft^2$)]
1948	0.78	(21)	8.8	(22.0)
1949	0.74	(20)	3.4	(8.5)
1950	14.5	(392)	109.8	(275.8)
1951	13.3	(359)	96.9	(243.4)
1952	11.2	(303)		

Source: Abee 1953.

the upper 15 cm (6 in.) of the soil in the lake bed declined appreciably during that period (Table A.12). The soil mass in the upper 15 cm (6 in.) of the lake bed was determined to be 1.6 to 1.8×10^2 kg/m^2 (1.4 to 1.6×10^6 lb/acre).

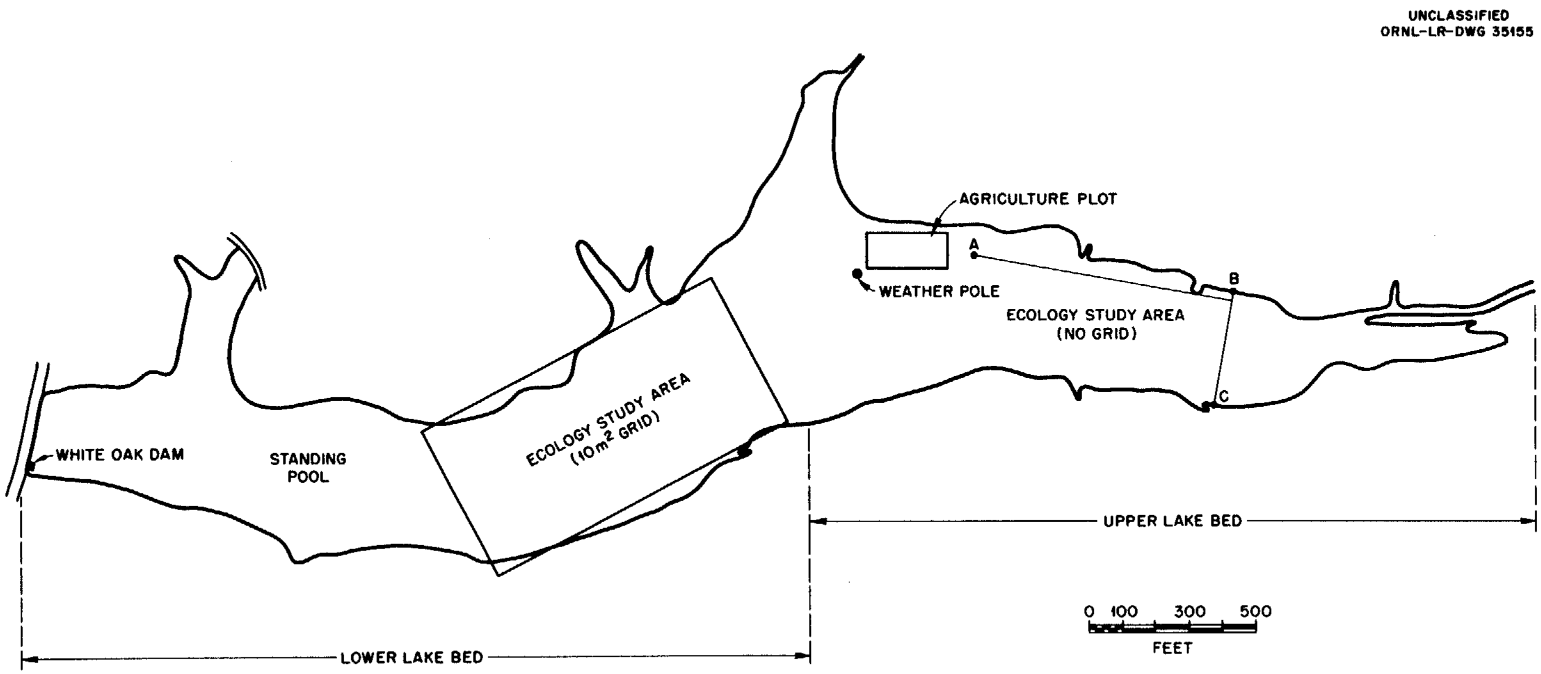
Three experimental agricultural soil plots were established on the lake bed in 1958 (Fig. A.11) (Auerbach et al. 1959). The results of analyses of soils in the agricultural area (Table A.13) indicate that Plot III had the largest concentrations of radioactivity, the greatest amount of exchangeable calcium and phosphorous, and the highest pH.

A detailed analysis and mapping of the radiation field above the upper and lower lake bed in 1958 (Fig. A.12) demonstrated a profound difference in the direct surface exposure dose rates in the two areas, resulting primarily from the higher concentrations of ^{137}Cs and ^{60}Co in the upper area (Lee and Auerbach 1959) shown in Table A.14. Average radionuclide concentrations in soil in the ecology study area in the lower part of the lake bed are shown in Fig. A.13. Concentrations of these radionuclides may be 50 to 100% higher in the inlet area of WOL (Oakes et al. 1982). The average readings of the radiation field surveys taken at a 100-cm height with a thin-walled ionization chamber were used to define the configuration of the radiation field above the lake bed. Dose rates varied from a low of nondetectable along the shore to a high of 30 mR/h at reference points along the creek bank. The average dose rate at a 100-cm height over the grid areas was 16 mR/h. Weekly fluctuations in the radiation field in the upper portion of the lake where radioactive material (^{106}Ru) was being deposited were up to 50 mR/h, primarily because of seepage from waste disposal pits upstream. Regions of lowest dose are along the shore lines, and maximum doses occur above the body of the lake bed. Transects of the dose rate above the two ecology areas also show this pattern (Fig. A.14). There is a positive correlation with the depth of associated silt and the radiation levels and a negative correlation between the dose rates and the depth of silt deposited at various distances from WOD. At 1006 m (3300 ft) from the dam, only

Table A.12. Changes in ^{90}Sr in White Oak Lake bed

Year	Concentration				Total lake bed	
	[kBq/100 g	(µCi/100 g)]	[MBq/m^2	Ci/acre)]	[TBq	(Ci)]
1956	5.07	(0.137)	8.14	(0.888)	1.31	(35.5)
1957	2.78	(0.075)	4.43	(0.483)	0.71	(19.3)
1958	1.67	(0.045)	2.69	(0.293)	0.43	(11.7)

Source: Auerbach et al. 1959.



White Oak Lake Bed

Fig. A.11. Map of White Oak Lake bed showing study areas, adapted from Auerbach et al. (1959). Source: Oakes et al. (1982).

Table A.13. Concentrations of radionuclides and chemical properties of agricultural soil plots in White Oak Lake Bed, 1958

Plots	^{90}Sr [kBq/100 g	^{90}Sr (μCi/100 g)]	^{137}Cs [kBq/100 g	^{137}Cs (μCi/100 g)]	^{60}Co [kBq/100 g	^{60}Co (μCi/100 g)]	Ca (meq/100 g)	K (meq/100 g)	Na (meq/100 g)	P (ppm)	pH
I	0.936	(0.0253)	10.3	(0.279)	4.63	(0.125)	17.7	0.34	0.33	2.1	6.95
II	0.762	(0.0206)	9.47	(0.256)	3.44	(0.093)	16.9	0.31	0.33	2.4	7.05
III	1.13	(0.0305)	35.1	(0.948)	5.59	(0.151)	21.2	0.28	0.27	3.2	7.39

Source: Auerbach et al. 1959.

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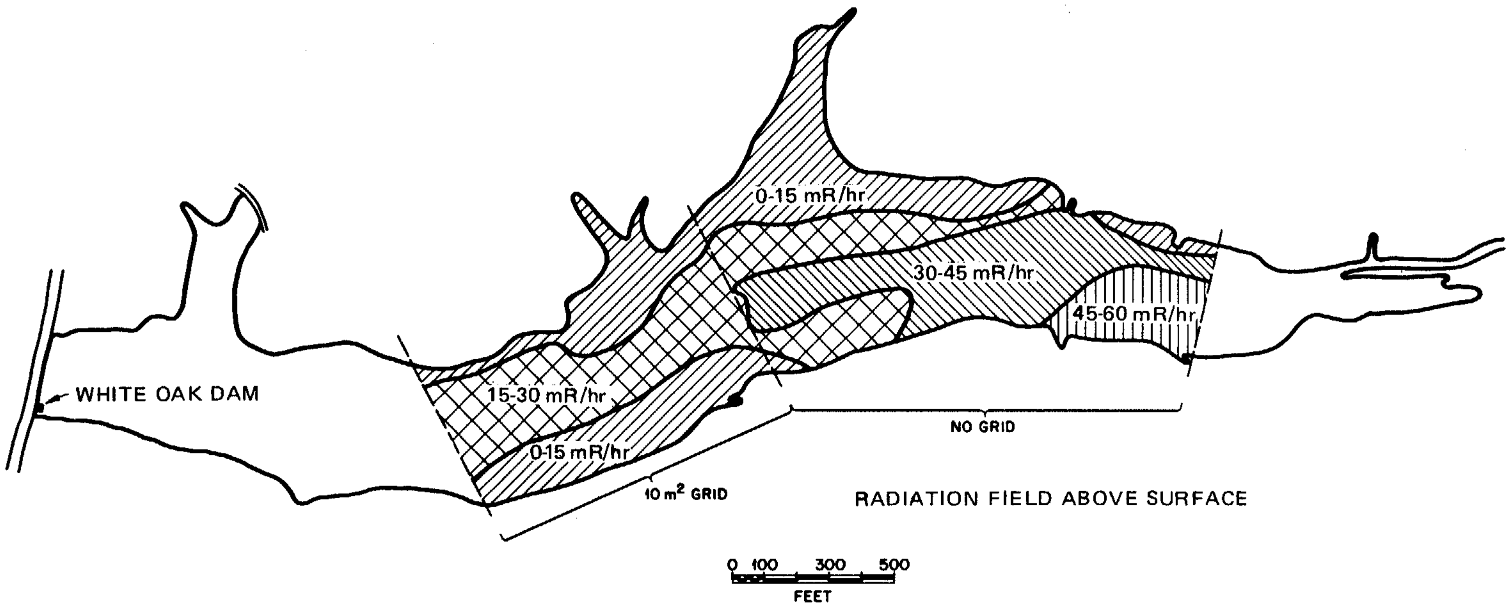

Ecology Study Areas
(White Oak Lake Bed)

Fig. A.12. Surface exposure dose rates 1 m above White Oak Lake bed in 15-mR/h increments, 1958, adapted from Lee and Auerbach (1959). Source: Oakes et al. (1982).

Table A.14. Comparison of upper and lower White Oak Lake soils in 1959

Constituent	Upper lake bed	Lower lake bed
^{90}Sr [kBq/100 g (μCi/100 g)]	2.01 (0.0544)	1.33 (0.036)
^{137}Cs [Bq/100 g (μCi/100 g)]	151.3 (4.089)	27.2 (0.734)
^{60}Co [Bq/100 g (μCi/100 g)]	39.2 (1.059)	29.9 (0.8068)
Ca (meq/100 g)	(36.0)	(20.1)
K (meq/100 g)	(0.195)	(0.221)
Na (meq/100 g)	(0.653)	(0.0366)
P (ppm)	(3.50)	(2.04)
pH	(7.53)	(6.67)

Source: Morgan et al. 1959.

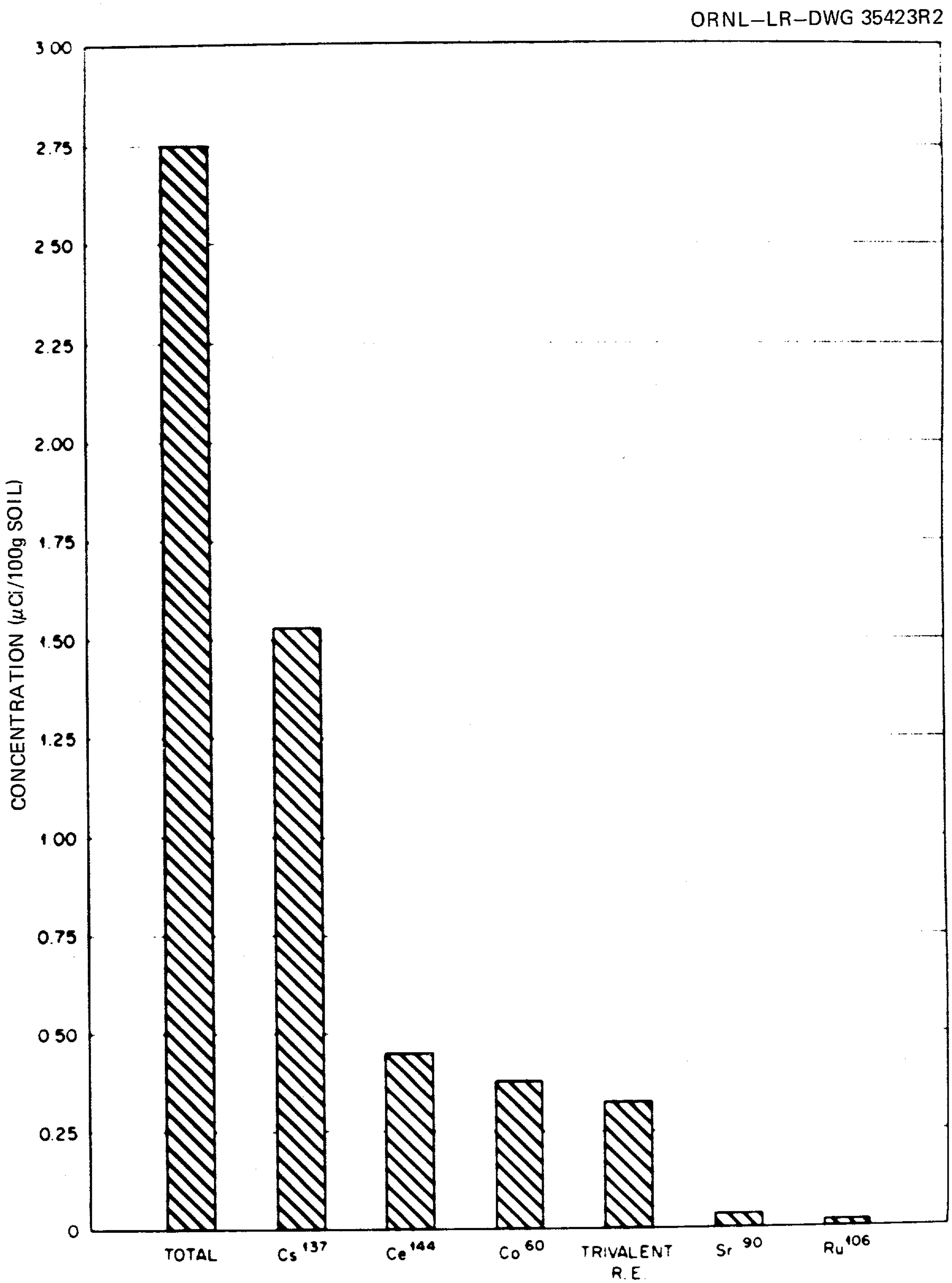

Fig. A.13. Average concentration of radionuclides present in the top 10.2 cm (4 in.) of WOL bed soil (grid area, 1958), adapted from Lee and Auerbach (1959). Note: multiplying the concentrations by 0.037 will convert μCi/100 g to MBq/100 g. Source: Oakes et al. (1982).

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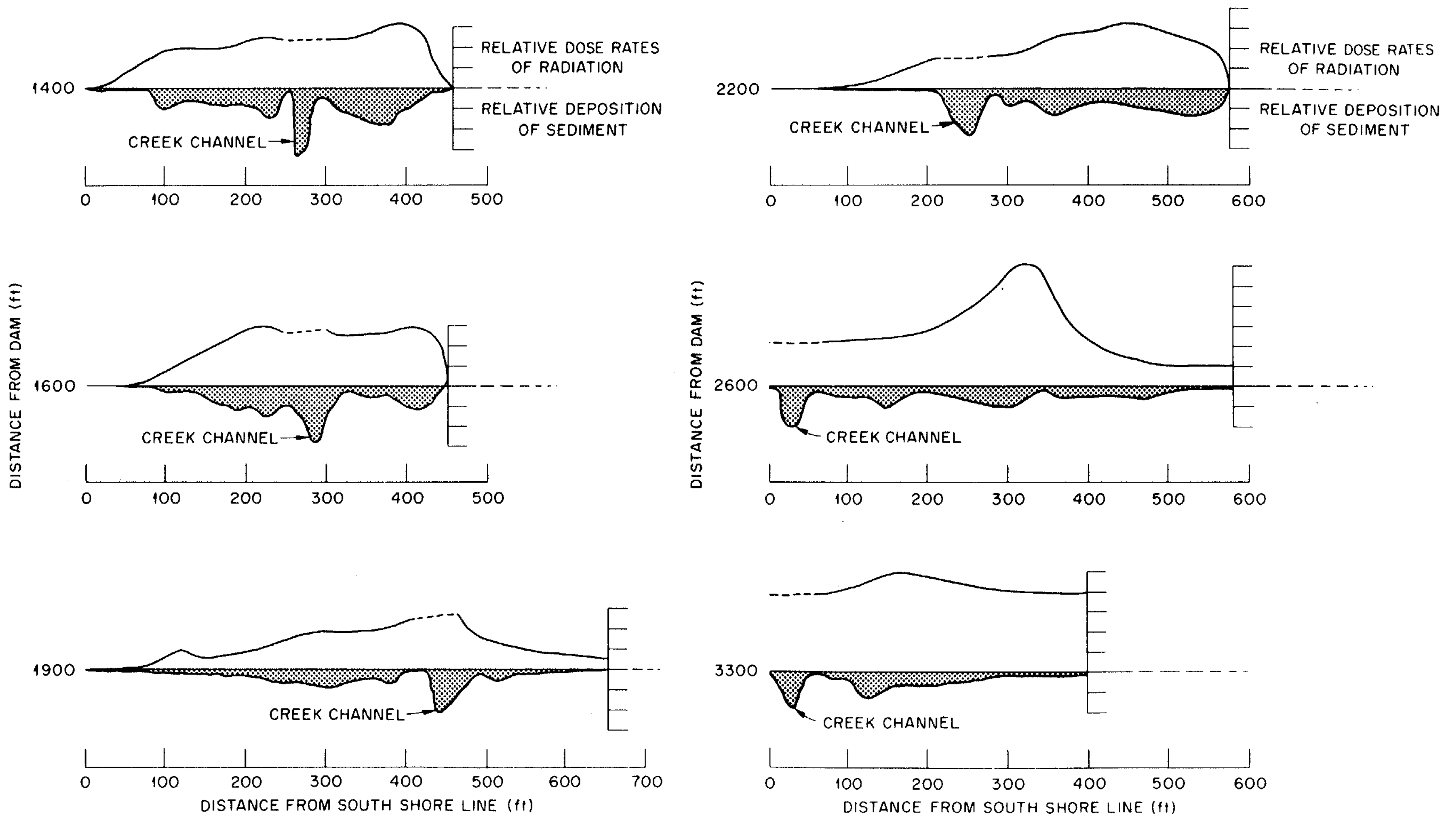

Fig. A.14. Sediment deposit and associated radiation field (White Oak Lake bed) at various transects above White Oak Dam, 1958, adapted from Lee and Auerbach (1959). Source: Oakes et al. (1982).

small depths of sediment are present but higher dose rates. At 427 m (1400 ft), there are relatively large amounts of silt but lower dose rates.

During 1961, Lomenick et al (1961) collected 1.8 m (6-ft) core samples along upper and lower lake bed transects, [WOC kilometer (WOCK) 2.1, WOC mile (WOCM) 1.3] and WOCK 1.4 (WOCM 0.9), to determine the vertical and lateral distribution of radionuclides in the lake bed. A summary of the gross gamma activity in 2.5-cm increments of the cores is given in Table A.15. These data generally indicate that (1) more gamma activity per gram of soil was detected at the upper lake bed [WOCK 2.1 (WOCM 1.3)] than the lower lake bed [WOCK 1.4 (WOCM 0.9)]; (2) most of the gamma activity was contained in the first 30 cm of soil; and (3) activity in the upper few centimeters of each core was rather uniformly distributed (Lomenick et al. 1961).

A study of ^{106}Ru distribution in WOC in 1962 indicated that most of the ^{106}Ru enters the upper few centimeters of the lake bed soil during the dry months when the water table is low, but it is transported laterally and vertically through the soil during the winter months when the water table lies relatively near the surface (Lomenick et al. 1962, Cowser et al. 1961).

A series of soil samples was taken within the lake bed during February 1962 and radiochemically analyzed to determine the distribution and total amount of ^{106}Ru in the soil. The cores, ranging in depth from 61 cm (24 in.) to 152 cm (60 in.), were taken approximately 15.2 m (50 ft) apart along lines at right angles to the surface flow of waste over the lake bed (Lomenick et al 1962). Calculations based on the results of the analysis of these samples indicate that the lake bed contained approximately 44 TBq (1200 Ci) of ^{106}Ru.

Also in 1962, a series of 250 core samples was taken within the WOL area at sites shown in Fig. A.15 and analyzed for ^{106}Ru, ^{137}Cs, ^{60}Co, Trivalent Rare Earth (TRE), and ^{90}Sr (Lomenick et al. 1963). The thickness of the sediment is shown in Fig. A.16. In general, most of the ^{137}Cs was associated with the relatively thin layer of the

Table A.15. Distribution of gross gamma activity in the bed of White Oak Lake, 1961

(Counts $min^{-1} g^{-1}$ wet weight)

Depth (cm)	Distance from left bank (m): Upper transect (White Oak Creek km 2.1)					Lower transect (White Oak Creek km 1.4)				
	15	24	43	53	73	27	58	76	104	125
0-2.5	21,300	36,500	16,700	32,500	18,540	3,000		15,700	8,000	8,700
2.5-5	19,800	30,600	29,400	28,000	13,700	6,000	14,000[a]	14,400	8,600	13,400
5-7.5	19,600	20,500	29,200	27,000	21,400	2,100		13,400	18,100	13,700
7.5-10	190	18,400	31,700	28,000	21,000	450	13,800[b]	18,700	24,500	14,400
10-12.5	110	23,800	27,800	25,000	20,500	15			26,100	16,500
12.5-15	10	63,000	21,400	43,100	11,000	15	17,300[c]	1,300[c]	24,400	13,000
15-23	10	57,900	23,500	21,000	4,900	230	2,100	65	3,300	2,900
23-30	6	8,700	28,600	5,500	3,200	5	450	10	100	700
30-46	35	1,400	6,800	2,000	1,500	15	300		80	95
46-61	30	800	1,800	500	1,400	5	7	450	7	30
61-91	2	600	300	400	1,400	5	100	6	10	5
91-122	2	180	100	270	750	5	3	10	7	5
122-152	750	50	75	170	630	2	3	2	8	6
152-183	90	25	85	200	700	3	5	3	3	15

[a]Total for depth of 0 to 2.5 cm.
[b]Total for depth of 0 to 10 cm.
[c]Total for depth of 0 to 15 cm.

Source: Lomenick et al. 1961.

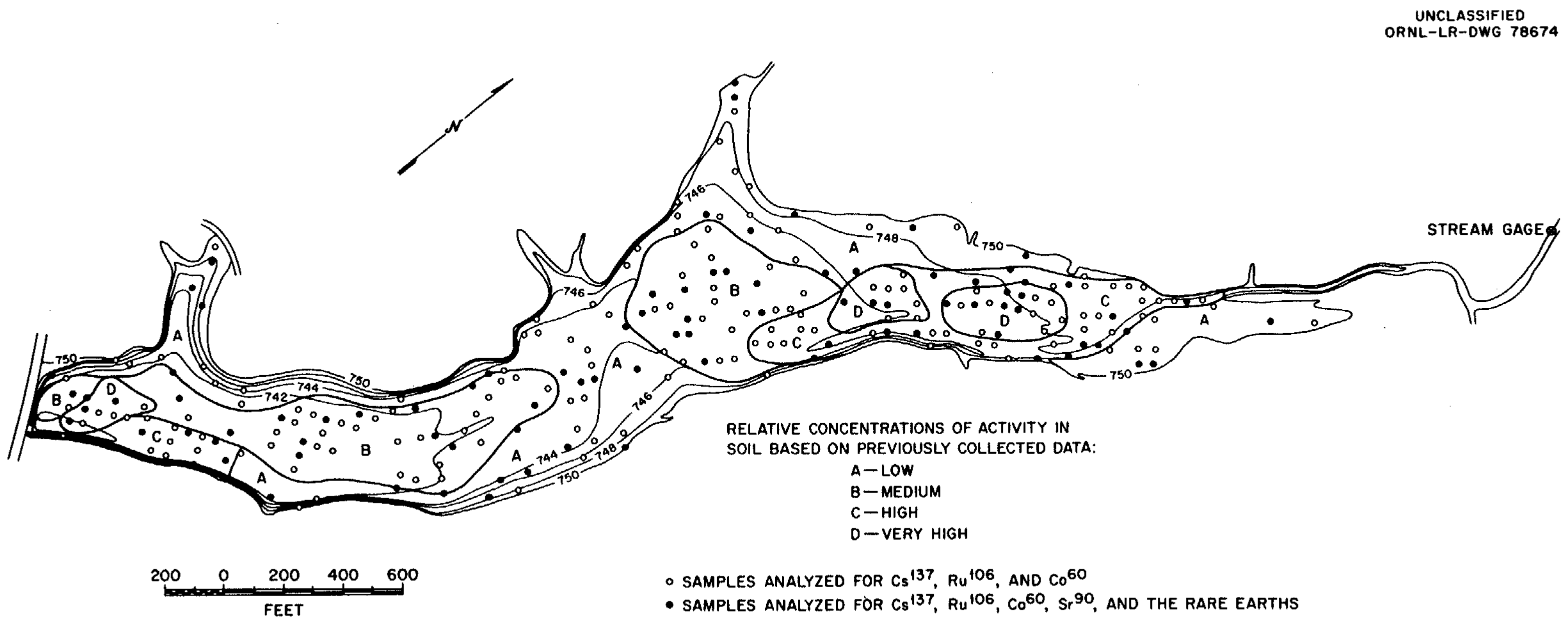

Fig. A.15. Location of 61-cm core samples in bed of White Oak Lake, 1962, adapted from Lomenick et al. (1963). Source: Oakes et al. (1982).

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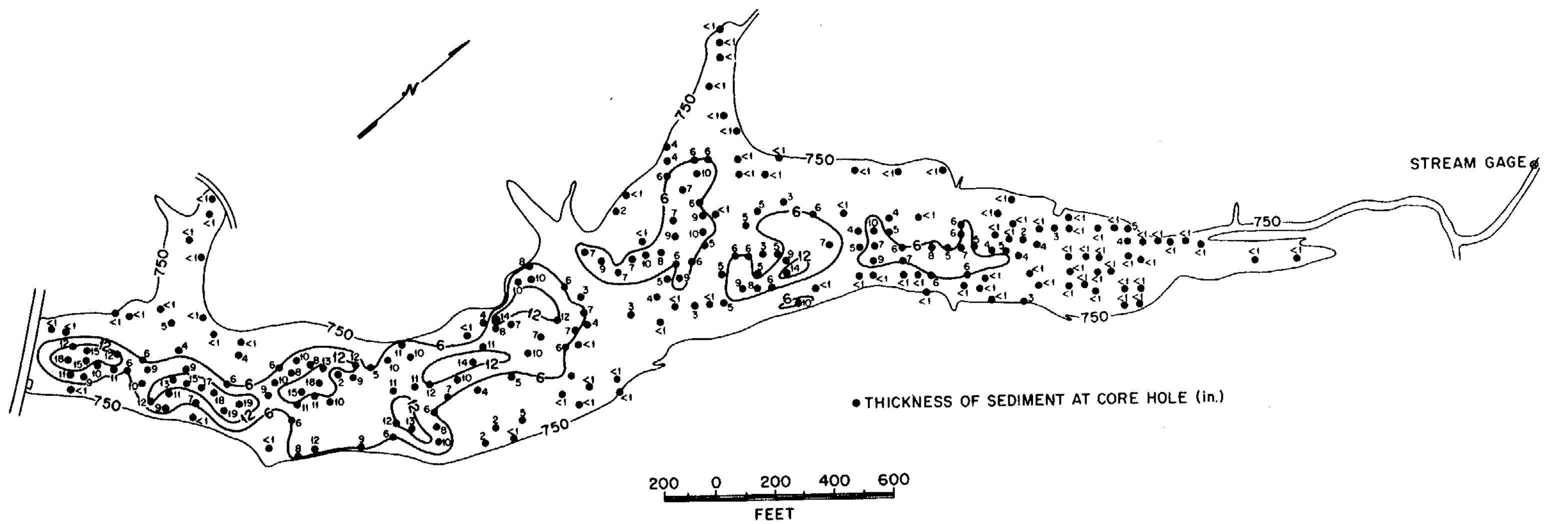

Fig. A.16. Map of White Oak Lake bed (1962) showing thickness of contaminated sediment, adapted from Lomenick et al. (1962). Note: multiplying inches by 2.54 will convert inches to centimeters. Source: Oakes et al. (1982).

recent lacustrine sediment that covered the lake bed. In areas near the shoreline, where the sediment is thinnest, the activity was lowest. For the first 15 cm of soil, the ^{137}Cs concentrations varied from <3.7 x 10^{-5} to 2.85 x 10^{-5} mBq/g (<1 x 10^{-3} to 77 x 10^{-3} µCi/g). The areas of maximum concentrations lie roughly along the course of WOC through the bed and in the present impoundment area behind the dam.

The highest concentrations of ^{90}Sr were found within the inundated area behind the dam, with the exception of a few narrow zones parallel to the creek in the upper part of the lake bed (Lomenick et al. 1963). The quantity and distribution of radionuclides in WOL bed in 1962 are given in Table A.16.

During 1964, a series of ten sediment ranges was established in WOC. Samples were collected from the upper 0.06 m (0.2 ft) of bottom sediment. The distribution of radionuclides in the 63-µm particle size fraction of the sediment is shown in Fig. A.17.

In 1964, it was determined that the sediment of WOL had accumulated 35.9 TBq (700 Ci) of ^{137}Cs (Lomenick et al., 1964). Nearly all the cesium in the lake bed is associated with lacustrine sediment. Figure A.18 shows the concentrations of cesium in several cores taken throughout the lake bed. There is little difference in the concentration of cesium in the cores where the sediment is only a few centimeters thick and in some of the cores where the sediment is up to 30 cm thick. There does not seem to be a relationship between sediment thickness and cesium concentration.

In 1970, sediment samples were obtained from the mouth of WOC entering the Clinch River and from WOL (Tamura et al. 1970). Results of the radionuclide distribution are given in Table A.17. The ^{137}Cs concentration in the creek, 0.21 kBq/g (5.8 x 10^{-3}µCi/g) was higher than in the lake bed sample, 0.07 kBq/g (1.9 x 10^{-3} µCi/g). The total ^{90}Sr content was similar in the creek and lake samples (Tamura et al. 1970).

Table A.16. Quantity and distribution of radionuclides in White Oak Lake bed, 1962
[Measurements are in TBq (Ci)]

Radionuclides	Depth from surface [cm (in.)] 0–15 (0–6)	15–30 (6–12)	30–45 (12–18)	45–60 (18–24)	Total
^{106}Ru	22 (594)	10.2 (276)	4.1 (112)	2.1 (56)	38.4 (1038)
^{137}Cs	17.3 (468)	7.6 (204)	1.1 (29)	0.1 (3)	26.1 (704)
^{60}Co	4.4 (119)	0.8 (22)	0.3 (8)	0.1 (3)	5.6 (152)
TRE[a]	0.5 (13)	0.1 (2.5)	0.004 (1.0)	0.004 (0.1)	0.64 (17.2)
^{90}Sr	0.4 (10)	0.1 (3.5)	0.004 (1.0)	0.004 (0.1)	0.54 (14.6)

[a]Trivalent rare earths less ^{90}Y.

Source: Lomenick et al. 1963.

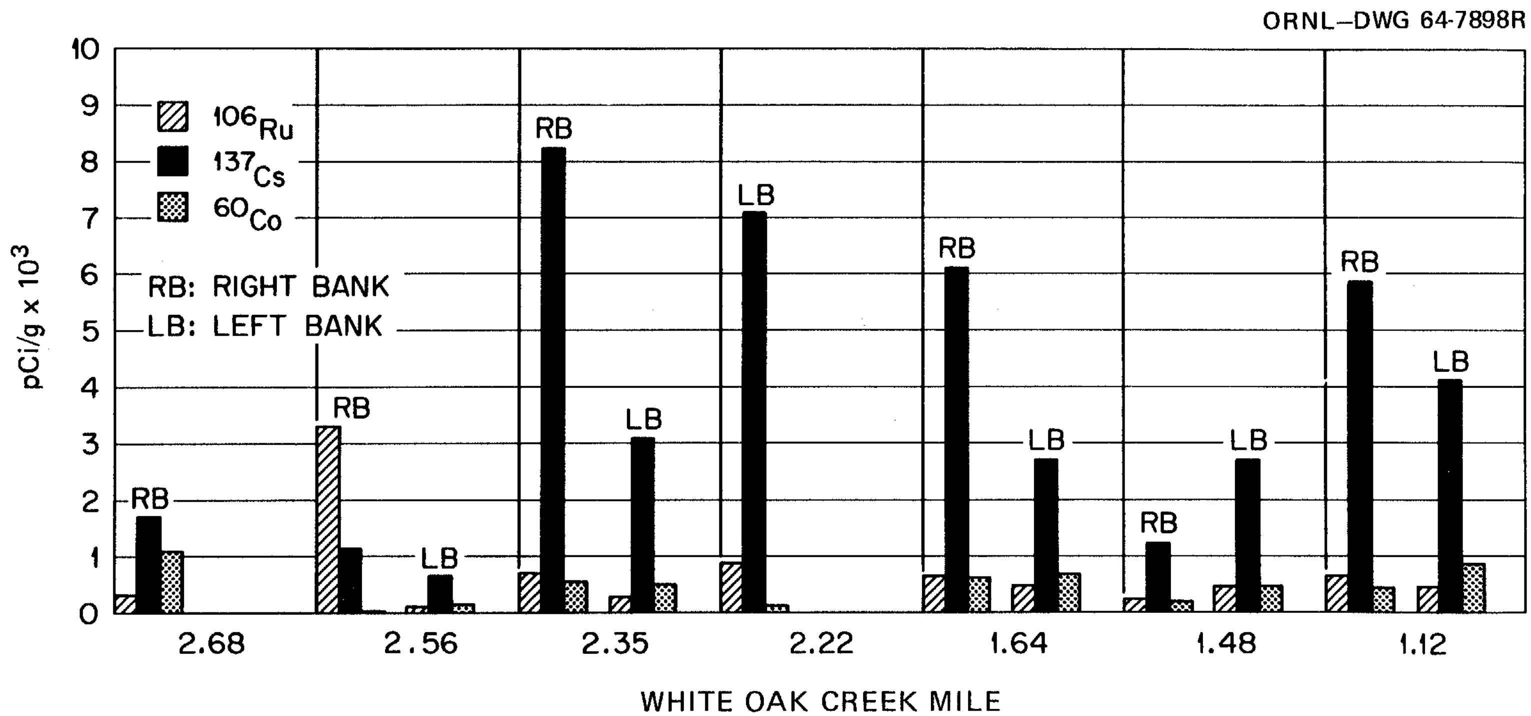

Fig. A.17. Distribution of radioactivity in White Oak Creek, 1964, adapted from McMaster and Richardson (1964). Note: multiplication of the locations by 1.61 will convert miles to kilometers; multiplying the concentrations by 0.037 will convert pCi/g to Bq/g. Source: Oakes et al. (1982).

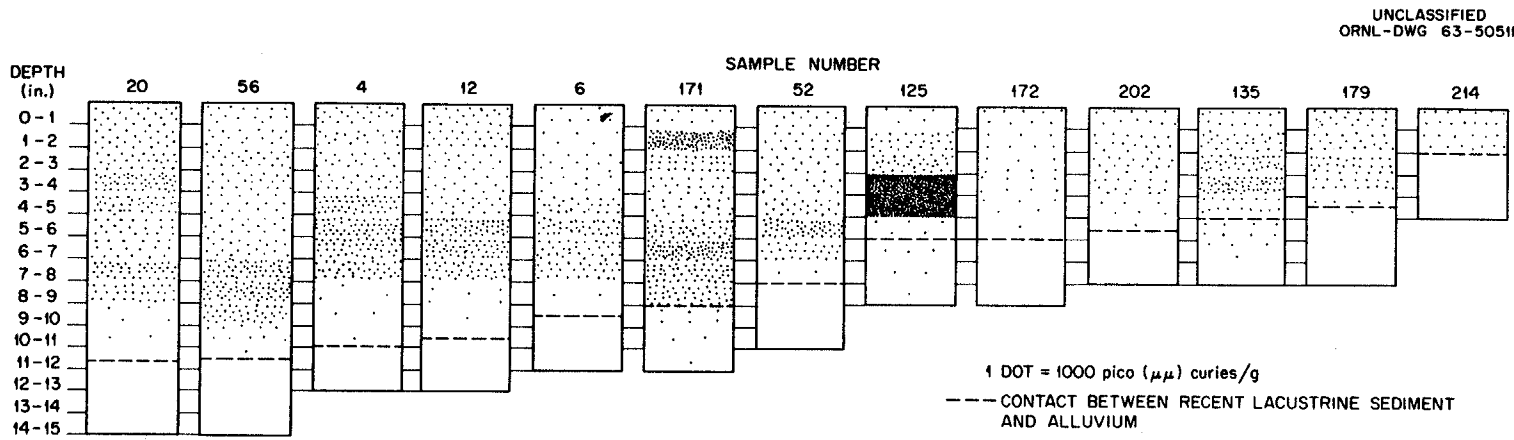

Fig. A.18. Concentration of ^{137}Cs in White Oak Lake core samples, adapted from Lomenick et al. (1964). Note: multiplication of the depths by 2.54 will convert inches to centimeters; multiplying the concentrations by 0.037 will convert pCi/g to Bq/g. Source: Oakes et al. (1982).

Table A.17. Distribution of ^{90}Sr and ^{137}Cs from sediments collected in White Oak Lake bed and the mouth of White Oak Creek, 1970

Band	Density (g/cm^3)	Weight (g)	Percent by weight	^{90}Sr (counts/min)	Percent in band	^{137}Cs (counts/min)	Percent in band	Band characteristics
				White Oak Creek				
1	1.86	0.0025	1.8	15	11.7	15	1.2	Amorphous material
2	1.86-2.30	0.0072	5.6	16	12.5	118	9.7	Amorphous material
3	2.30-2.41	0.0230	17.7	33	25.8	456	37.4	Clay minerals
4	2.41-2.47	0.0220	17.0	10	7.8	212	17.4	Clay minerals with feldspars
5	2.47-2.56	0.0562	43.3	25	19.5	281	23.1	Primarily quartz; some clay minerals
6	2.56-2.78	0.0143	11.0	10	7.8	77	6.3	Mica and chlorite (?)
7	2.78	0.0045	3.5	19	14.8	59	4.8	Heavy minerals, including dolomite
Total		0.1287		128		1218		
unbanded		0.1500		132		1326		
				White Oak Lake bed				
1	1.86	0.0013	1.0	5	3.8	8	2.2	Amorphous material
2	1.86-2.30	0.0012	0.9	7	5.3	23	6.3	Amorphous material
3	2.30-2.47	0.0486	35.8	37	28.0	148	40.5	Clay minerals includes band 4
4								Clay minerals includes band 4
5	2.47-2.59	0.0552	40.6	30	22.7	101	27.7	Primarily quartz; some calite and clay materials
6	2.59-2.78	0.0267	19.17	44	33.3	65	17.8	Primarily calcite
7	2.78	0.0029	2.1	9	6.8	20	5.5	Heavy minerals including dolomite
Total		0.1359		132		365		
unbanded		0.1500		105		406		

Source: Tamura et al. 1970.

Blaylock et al. (1972) conducted a study to update an assessment of the concentration of radionuclides in the bottom sediment of WOL. The mean concentration and the percentage of the total site activity are given in Table A.18. Cesium-137 was the most abundant radionuclide in the sediment and accounted for 62 to 86% of the total gamma emitters with only two sampling sites being the exception.

Earlier investigations indicated that the upper 15 cm (6 in.) of the sediments contained more than 65% of the ^{137}Cs and ^{90}Sr, 80% of the ^{60}Co, and 55% of the ^{106}Ru (Lomenick and Gardiner 1965). Most of the activity in the Blaylock study was not in the upper 15 cm (6 in.) of sediment as it was in the 1965 sampling (Lomenick and Gardiner 1965) but was at a deeper location, between 16 to 34 cm. This was expected because the annual discharges of radionuclides to WOL had decreased between 1965 and 1972, and additional sedimentation had covered most of the older contaminated sediments (Blaylock et al. 1972).

The concentration of ruthenium decreased considerably between 1965 and 1972. Radioactive decay and reduction in released ruthenium are the major factors contributing to this decrease. The largest concentrations of ^{137}Cs, ^{90}Sr, and ^{65}Zn were found in the upper shallow portion of the lake.

During 1977, tritium concentrations in WOL sediments were investigated (Blaylock and Frank 1979). The bound ^{3}H was determined using freeze-drying techniques. The concentration of ^{3}H in the overlying water was 648 pCi/ml compared to 450 pCi/ml in the water removed from the sediment. The dried sediment contained 17 pCi/g of ^{3}H. Approximately 11% of the dried WOL sediment was organic material. It was assumed that the ^{3}H in the sediment was organically bound, resulting in concentrations within the range of tritium found in the tissue bound tritium of plants and animals in the lake (Oakes et al. 1982).

To arrive at an accurate assessment of the radioactivity present in WOL, sediment samples were taken in December 1979 at locations shown in Figure A.19. The samples were taken near the dam since it was postulated that this location posed the greatest potential for release

Table A.18. Summary of radionuclide concentrations of bottom sediments for White Oak Lake, 1972

Site No.	^{106}Ru Bq/g (pCi/g)	%	^{137}Cs Bq/g (pCi/g	%	^{125}Sb Bq/g (pCi/g)	%	^{65}Zn Bq/g (pCi/g)	%	^{60}Co Bq/g (pCi/g)	%
1	3.5 (94.5)	5.4	50.5 (1364.3)	78.1	2.0 (55.4)	3.2	0 (0)	-	8.6 (232.1)	13.3
2	9.0 (243.1)	5.3	132.3 (3575.1)	77.9	5.4 (145.6)	3.2	1.6 (43.6)	1.0	21.4 (579.3)	12.7
3	14.7 (396.4)	7.0	129.9 (3510.7)	62.4	5.3 (143.1)	2.6	2.0 (54.6)	1.0	56.4(1524.4)	27.1
4	20.2 (546.6)	7.9	163.7 (4424.6)	63.9	10.4 (280.0)	4.1	5.1 (137.8)	2.0	56.7(1533.7)	22.2
5	10.0 (270.9)	5.6	130.6 (3528.7)	72.8	4.8 (128.4)	2.6	3.1 (84.7)	1.7	30.9 (835.5)	17.2
6	2.7 (73.4)	4.2	52.6 (1420.7)	80.2	0.7 (18.9)	1.1	0 (0)	-	9.8 (265.5)	14.6
7	2.8 (75.7)	4.3	51.3 (1385.5)	80.6	0.9 (25.4)	1.4	0 (0)	0	9.1 (246.3)	13.7
8	0.15(4.0)	5.4	2.5 (67.4)	85.0	0.1 (2.7)	3.5	0.02 (0.5)	0.9	0.1 (4.0)	5.1
9	1.2 (33.0)	5.5	20.3 (548.2)	85.8	0.9 (23.6)	4.0	0.03 (0.7)	0.1	1.1 (29.5)	4.2
10	3.5 (95.8)	5.2	57.1 (1543.0)	85.4	2.2 (58.9)	3.3	0.1 (3.3)	0.2	4.0 (107.4)	6.0

Source: Blaylock et al. 1972.

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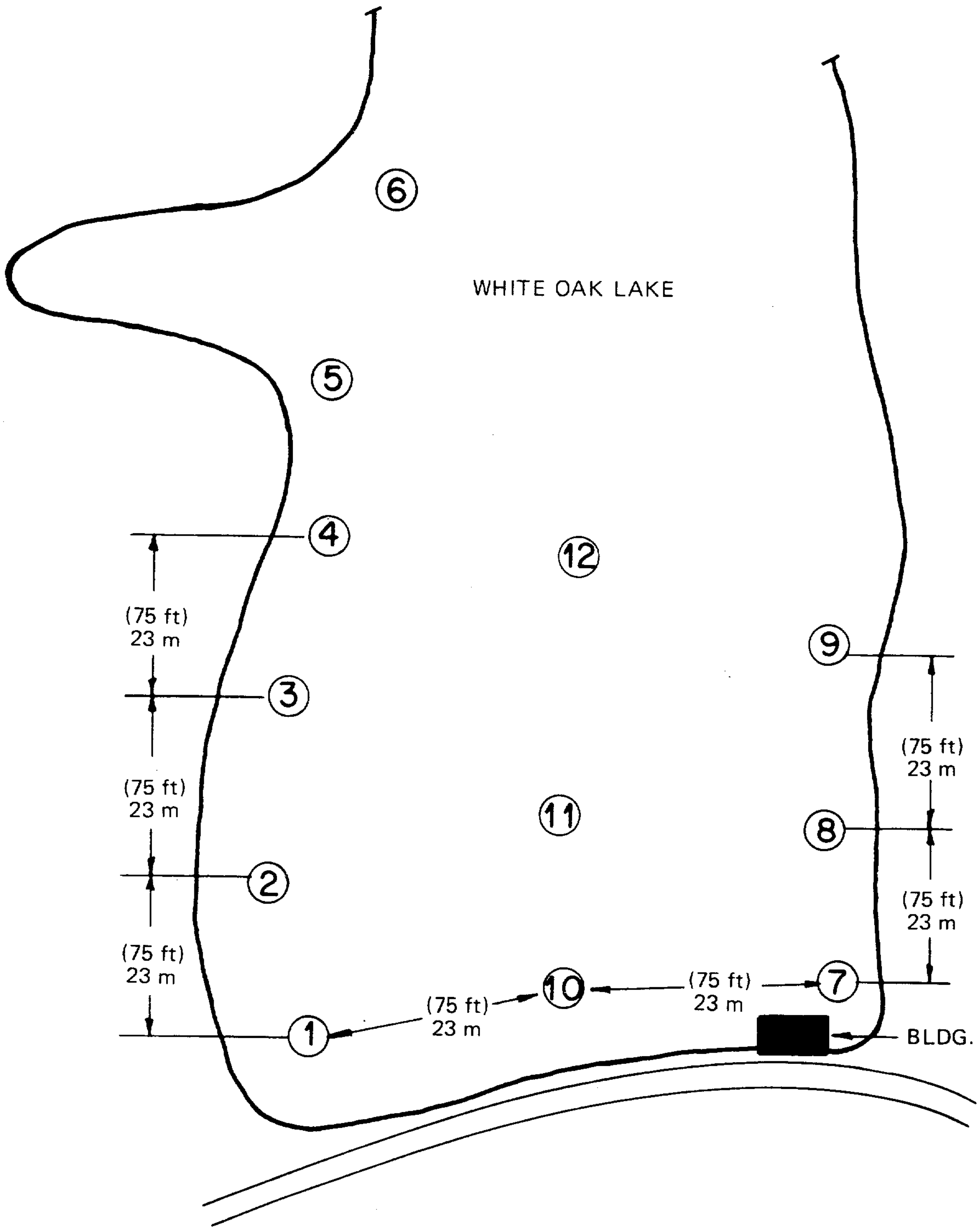

Fig. A.19. Map of White Oak Lake showing sampling locations, 1979. Source: Oakes et al. (1982).

to the public. The cores were divided into 2.5 cm (1 in.) segments in order that a depth profile could be performed. The average values for the cores are presented in Table A.19. The data for the top 15 cm (6 in.) of these cores are given by 2.5 cm (1 in.) segments in Tables A.20, A.21, and A.22. When assessing the data, it was noted that ^{60}Co decreased with depth, ^{137}Cs increased with depth (up to 15 cm), ^{90}Sr remained relatively constant with depth.

In order to obtain an estimate of the activity stored in the sediments in WOL, it was first necessary to ascertain the spatial relationship of the available core data. To do this, the sediment input of 2832 m^3/year (100,000 ft^3/year) was used to calculate how the sediment thickness changed with time (Oakes et al. 1982). The results of this calculation showed that the 15 cm (6 in.) core taken in 1979 (Tables A.20, A.21, and A.22) began where the 15 cm core taken in 1972 (Table A.18) ended. However, the 1972 core began 6.4 cm (2.5 in.) above where the 1962 core (Table A.16) ended. Since no data were available on this intervening time (between 1962 and 1972), the 1972 core data were used to represent the activity in this region.

Thus, activity data on a 98 cm (38.4 in.) cross section of the sediment became available. The volume of the sediments was calculated to be 1.3×10^5 m^3 (4.6×10^6 ft^3). Using a sediment density of 1.1 g/cm^3, the total activity in the sediments could be estimated (Oakes et al. 1982). The total activity in WOL sediments is estimated to be 23.8 TBq (644 Ci) which is made up of the following nuclides: ^{137}Cs, 21.9 TBq (591 Ci); ^{60}Co, 1.2 TBq (33 Ci); ^{90}Sr, 0.74 TBq (20 Ci) (Oakes et al 1982). TRU data are only available for the top 15 cm (6 in.) and indicate 0.03 TBq (0.87 Ci) of TRU nuclides: ^{238}Pu, 0.004 (0.096); ^{239}Pu, 0.01 (0.250); ^{241}Am, 0.001 (0.024); ^{244}Cm, 0.02 (0.498).

The sediment immediately downstream of WOD [WOCK 0.0-0.1 (WOCM 0.0-0.6)] was sampled during 1978-1979, at the locations indicated on Figure A.20. Cores were prepared by extracting the moist soil in 2.5 cm increments directly into a plastic dish, 7.1 cm diameter

Table A.19. Sediment data (pCi/g wet), White Oak Lake, 1979

Core sample	^{60}Co[a]	^{137}Cs[a]	$^{152,154}Eu$[a,b]	^{90}Sr[c]
1	123	617	16	37
2	131	447	11	39
3	87	420	6	32
4	76	348	10	29
5	108	545	10	85
6	66	377	12	32
7	94	328	16	28
8	58	133	10	29
9	104	339	12	55
10	110	725	18	38
11	93	722	18	33
12	96	701	20	55
Average	96	475	13	41

[a]Average of six 2.5 cm (1 in.) segments.
[b]Eu-154 is approximately 1.4 times the Eu-152 concentration.
[c]Average of top 2.5 cm (1 in.) segment and bottom 2.5 cm (1 in.) segment.

Source: Oakes et al. 1982.

Table A.20. Cesium-137 concentration in White Oak Lake cores, 1979
[Bq/g (pCi/g)]

Core	Depth (cm)					
number	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0
1	16.2 (439)	18.1 (489)	21.5 (580)	22.8 (617)	28.2 (763)	30.1 (814)
2	13.4 (363)	15.1 (409)	17.5 (474)	17.8 (482)	18.3 (495)	16.9 (458)
3	10.8 (292)	11.8 (319)	11.4 (308)	12.2 (330)	18.5 (499)	28.5 (769)
4	13.5 (365)	17.5 (472)	16.4 (442)	18.5 (501)	10.1 (274)	2.1 (57.7)
5	15.5 (420)	16.3 (440)	16.4 (443)	19.3 (521)	25.6 (692)	27.9 (754)
6	13.8 (372)	13.3 (360)	13.5 (364)	14.2 (383)	13.7 (371)	15.2 (410)
7	18.7 (506)	17.2 (465)	16.8 (454)	14.2 (384)	4.8 (129)	1.2 (31.3)
8	10.4 (280)	7.8 (211)	6.1 (165)	2.8 (77)	1.6 (44)	0.8 (22)
9	9.5 (256)	11.4 (309)	10.2 (275)	13.9 (377)	14.9 (402)	15.4 (415)
10	18.2 (492)	22.0 (595)	25.9 (700)	29.8 (805)	31.9 (862)	33.1 (895)
11	18.4 (497)	23.2 (627)	27.9 (754)	30.2 (816)	30.2 (816)	30.5 (824)
12	17.8 (481)	23.1 (624)	27.2 (735)	28.6 (773)	27.9 (754)	31.0 (838)

Source: Oakes et al. 1982.

Table A.21. Cobalt-60 concentration in White Oak Lake cores, 1979
[Bq/g (pCi/g)]

Core	Depth (cm)					
number	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0
1	5.8 (157)	5.1 (138)	5.0 (134)	4.1 (111)	3.9 (105)	3.5 (95.4)
2	5.8 (156)	5.1 (137)	5.2 (141)	4.8 (130)	4.3 (117)	3.8 (102)
3	3.9 (104)	2.9 (77)	2.9 (79)	2.9 (79)	3.1 (83)	3.8 (102)
4	4.6 (124)	4.4 (119)	3.2 (87)	3.1 (84)	1.2 (32.4)	0.3 (9.1)
5	4.1 (111)	3.9 (106)	3.4 (92.8)	3.9 (106)	4.2 (114)	4.3 (117)
6	2.8 (74.5)	2.8 (74.7)	2.7 (72.0)	2.2 (60.4)	2.1 (55.8)	2.1 (57.5)
7	4.4 (118)	3.9 (104)	4.6 (124)	5.0 (134)	2.4 (63.4)	0.9 (23.0)
8	5.7 (153)	3.2 (85.3)	2.0 (53.9)	1.0 (26.7)	0.7 (18.6)	0.3 (8.9)
9	7.3 (197)	5.3 (144)	3.0 (79.8)	2.4 (65.6)	2.6 (69.3)	2.6 (68.9)
10	5.8 (157)	4.4 (119)	3.7 (100)	3.8 (103)	3.7 (100)	3.0 (81.1)
11	4.5 (122)	3.2 (86.5)	3.1 (83.8)	3.3 (89.2)	3.2 (86.5)	3.3 (89.2)
12	4.5 (122)	3.9 (105)	3.0 (81.1)	3.5 (94.6)	3.2 (86.5)	3.3 (89.2)

Source: Oakes et al. 1982.

Table A.22. Strontium-90 concentration in White Oak Lake cores, 1979 [Bq/g (pCi/g)]

Core number	Depth (cm)	
	0-2.5	12.5-15.0
1	1.4 (37)	1.3 (36)
2	1.7 (47)	1.1 (31)
3	1.3 (34)	1.1 (30)
4	1.1 (29)	1.0 (28)
5	2.5 (69)	3.7 (100)
6	1.0 (28)	1.3 (36)
7	1.3 (35)	0.7 (20)
8	0.8 (22)	1.3 (35)
9	1.1 (31)	2.9 (78)
10	0.9 (23)	1.9 (52)
11	1.3 (34)	1.2 (32)
12	1.9 (51)	2.2 (59)

Source: Oakes et al. 1982.

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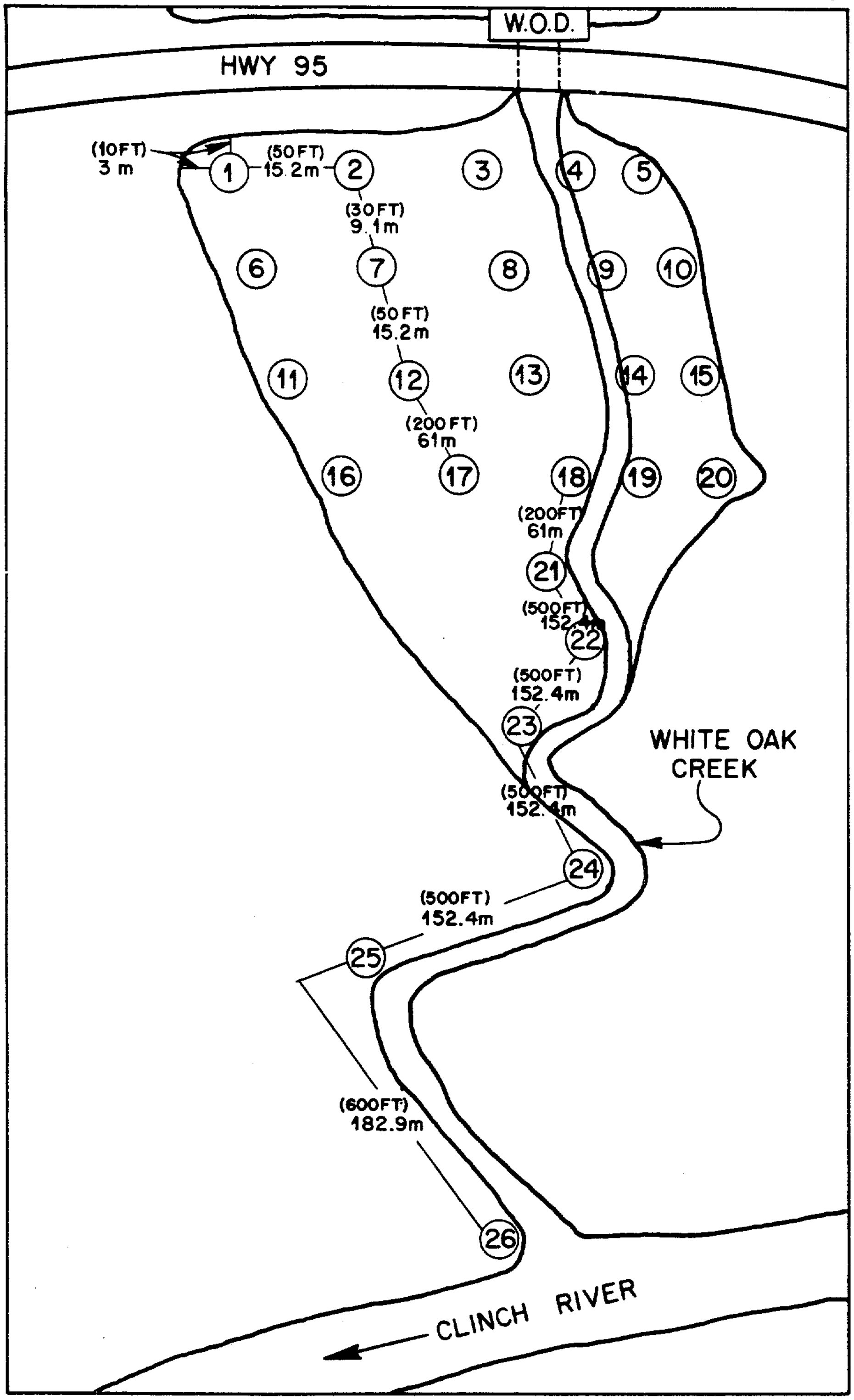

Fig. A.20. Sediment sampling locations in WOC, December 1979. Source: Oakes et al. (1982).

by 2.8 cm height. The data for ^{137}Cs and ^{60}Co in the first 43 cm (15 in.) of all cores are presented in Figures A.21 and A.22. Concentrations of ^{137}Cs for the 88.9 cm depth of core 23 are presented in Figure A.23. This core was taken at the first sharp bend in the creek below WOD (see Fig. A.20). The sediment buildup is interesting in that the highest concentrations were 66 cm (26 in.) below the surface; a concentration of 2250 Bq/g (60,700 pCi/g) for ^{137}Cs was observed (Oakes et al. 1982). This peak concentration could correspond to the high ^{137}Cs discharge in 1956 (see Table A.8).

A.3.2 Groundwater

A.3.2.1 Occurrence. Groundwater occurs in all four formations which underlie the WOC Basin. The dolomite of the Knox Group on Chestnut Ridge and the Chickamauga Limestone underlying Bethel Valley are the principal water bearing units. The Rome Formation on Haw Ridge and the Conasauga Group underlying Bethel Valley are thought to contain only small quantities of water. Water occurs in the weathered rock of all of the units. In the Knox and Chickamauga, appreciable flow occurs at greater depths in fractures and enlarged openings developed by dissolution of the carbonate rock. In the siltstone and shale of the Rome Formation and the Conasauga Group, water occurs in small openings along joints and bedding planes (Webster 1976). Openings in these rocks have not undergone substantial enlargement because the rocks are relatively insoluble (McMaster 1967).

A pressure test of one well in the Chickamauga Limestone at X-10 and the examination of cores from several wells in that unit indicated that solution channels decrease in number and size with increasing depth; thus suggesting that these channels and the circulation of groundwater in the Chickamauga may be restricted to the upper several hundred feet. Pressure tests of a few wells in the interbedded silt, shale, and limestone strata of the Conasauga in Melton Valley indicate that secondary openings are restricted largely to the upper 100 feet and are rarely found as deep as 200 feet. Thus, there appears to be

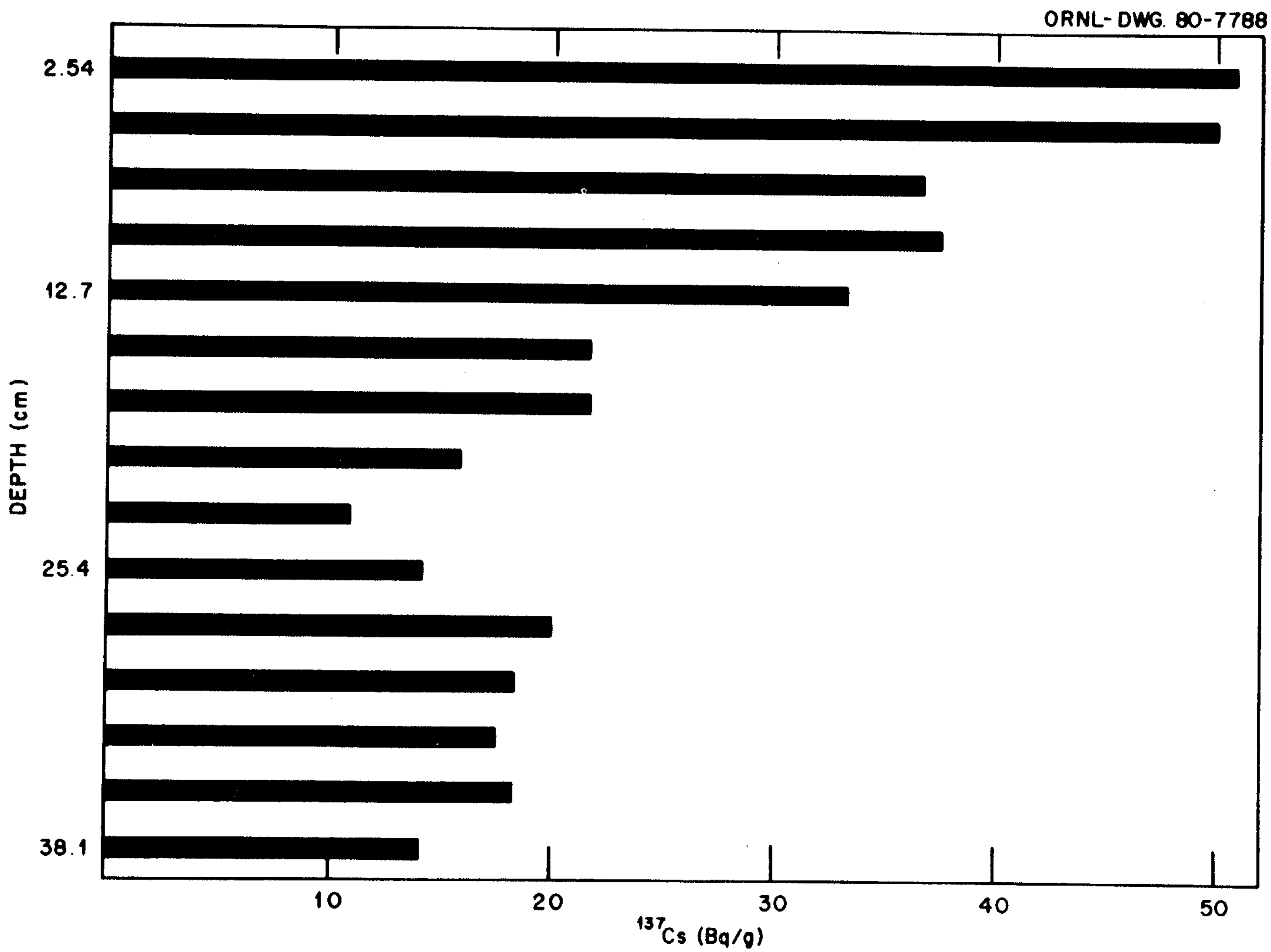

Fig. A.21. ^{137}Cs content (Bq/g) in WOC sediment, 1978 sampling program. Source: Oakes et al. (1982).

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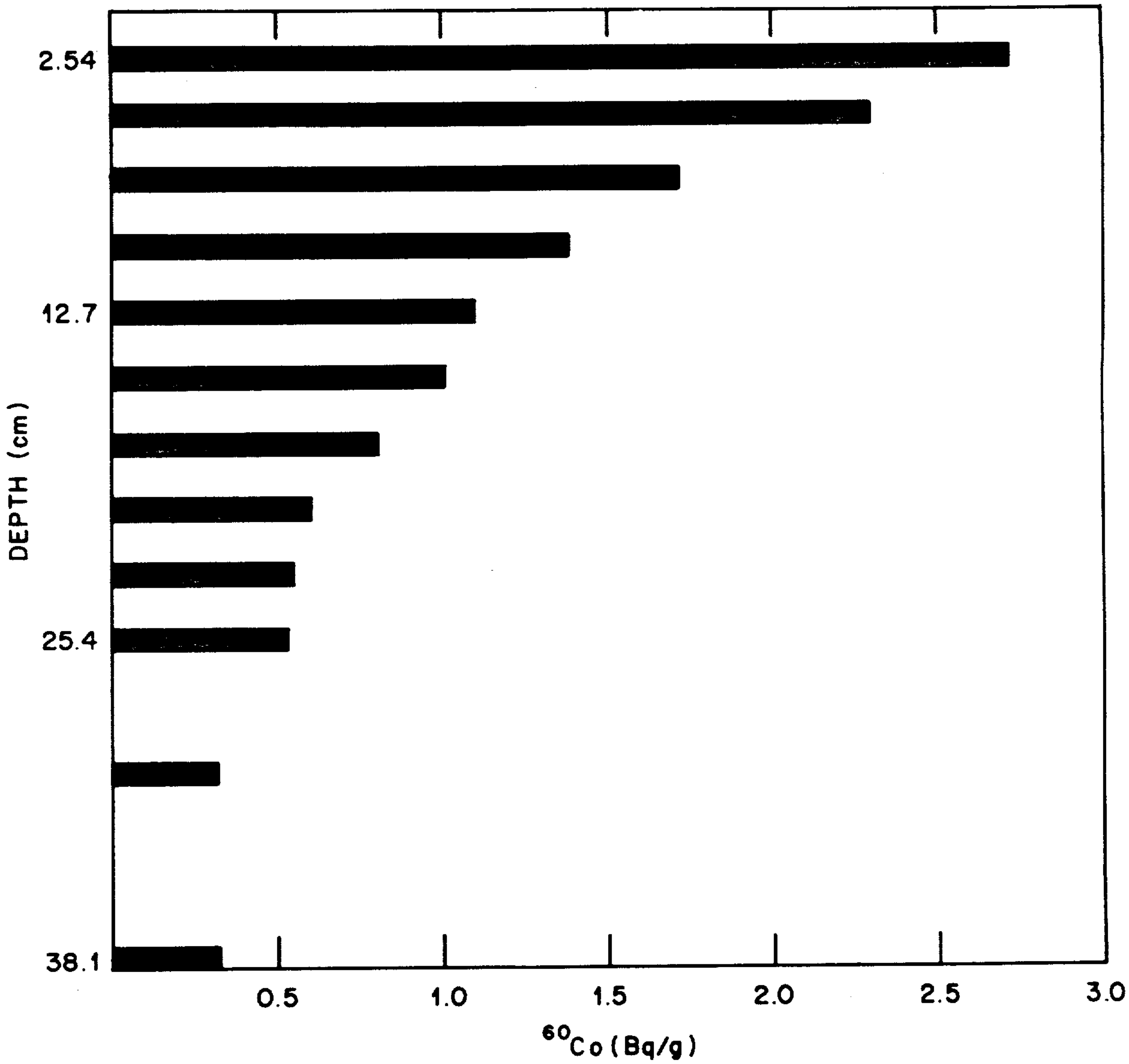

Fig. A.22. ^{60}Co content (Bq/g) in WOC sediment, 1978 sampling program. Source: Oakes et al. (1982).

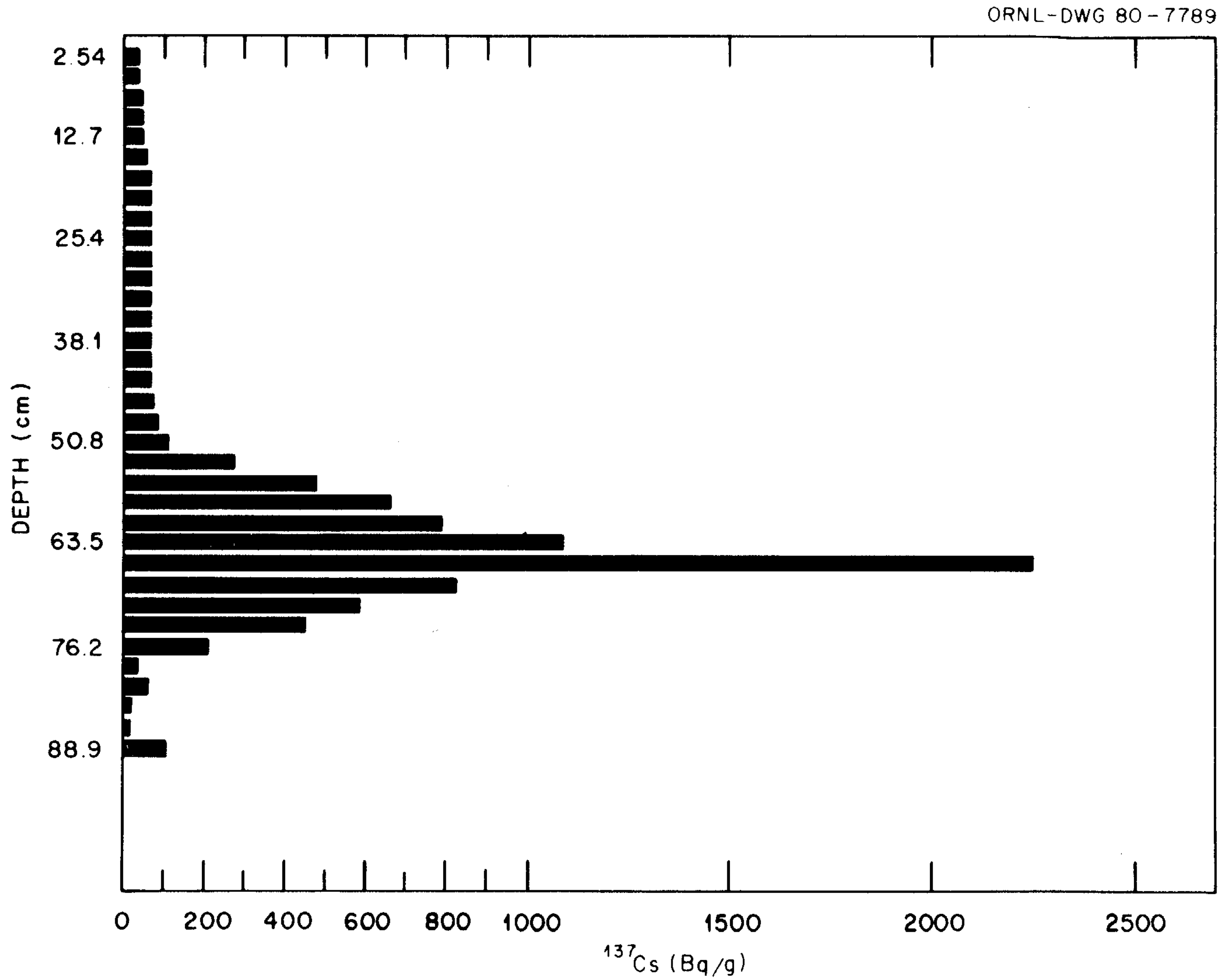

Fig. A.23. ^{137}Cs content in core 23, 1978 sampling program. Source: Oakes et al. (1982).

little significant groundwater circulation below that depth. However, the extent and depth of groundwater circulation in the Maryville limestone of the Conasauga underlying WOL and Dam (Fig. A.24) have not been investigated (Webster 1976). The flow of groundwater and possible contaminants under and around the dam toward the CR is an important environmental concern.

Water table contour maps for the entire watershed are not available, however, maps for SWSAs 3, 5, 6, and the pits and trenches area prepared during past studies are shown in Figures A.25-A.28. These maps indicate that the water table generally follows the topography of the land surfaces but in a subdued fashion as seen in the maps, all of the waste storage areas are directly upgradient from WOC or its tributaries. Since liquid waste is no longer being added to the pits and trenches, the water levels shown in Fig. A-27 are probably not representative of the levels at this time. Because of the complex nature of the local geology, great care is required to insure that water level measurements represent the water table rather than the effects of well construction or sharp differences in permeability, faults, or fractures and joints in the formations.

A.3.2.2 Aquifer Properties. The only large scale aquifer test data available in the watershed was collected during pumping tests conducted to determine the transmissivity and storage coefficients at the Engineered Test Facility (ETF) at SWSA 6 (Fig. A.28) adjacent to WOL (Vaughan et al. 1982, Davis et al. 1984, and Smith and Vaughan, 1985a). In the longest test, well number 12 was pumped at a rate of 3.29 L/min. for 24 hours and drawdowns were monitored in the pumped well and wells 1 through 11. Well locations and lines of equal drawdown after 24 hours of pumping are shown in Figure A.29 and drawdown versus time in selected wells is shown in Figure A.30 (Davis et al. 1984).

The elongated shape of the drawdown pattern (non-cylindrical) clearly indicates the heterogeneity of the aquifer. The elongated pattern is most likely the result of variable hydraulic conductivity in the media (high permeability along strike) and structural control of

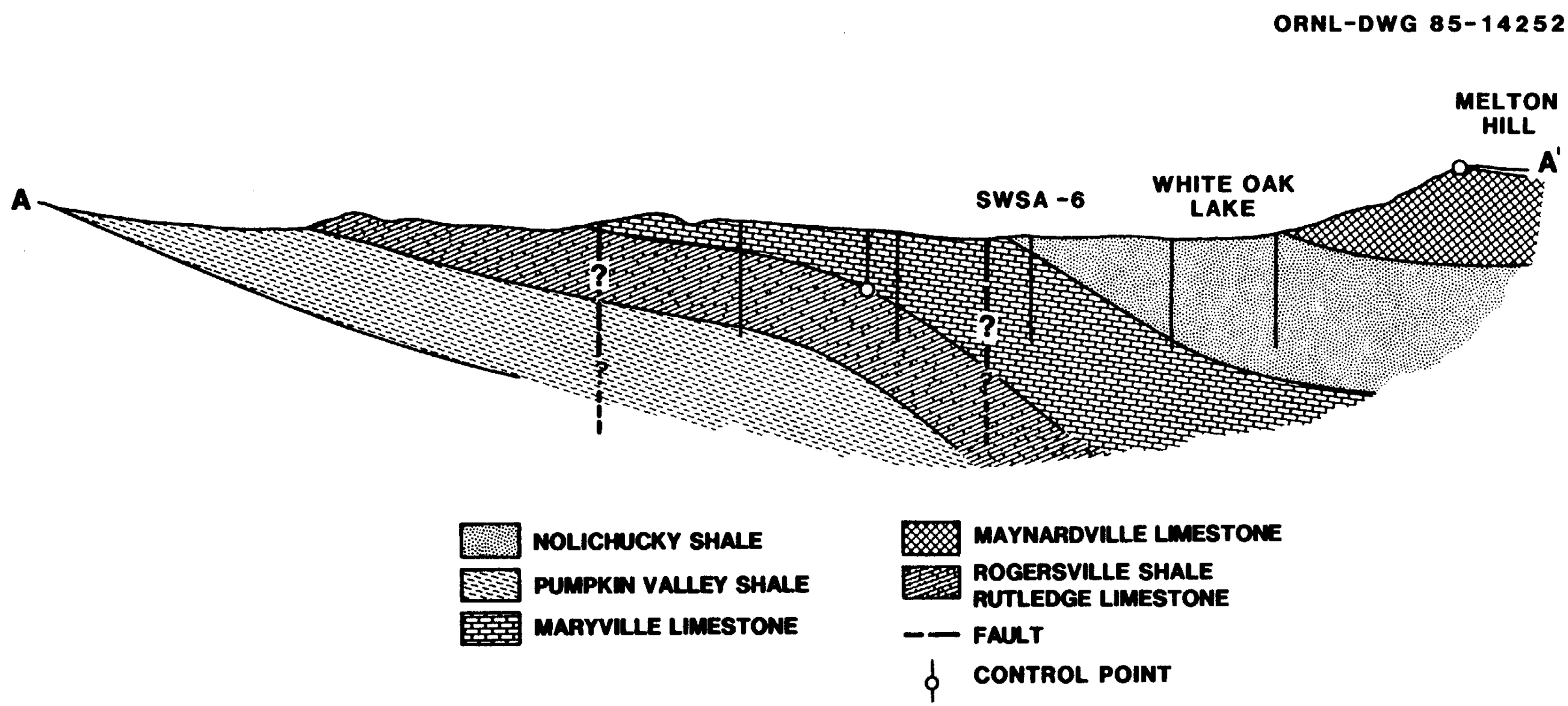

Fig. A.24. Generalized geologic cross section through SWSA-6. Source: Boegly et al. (1985).

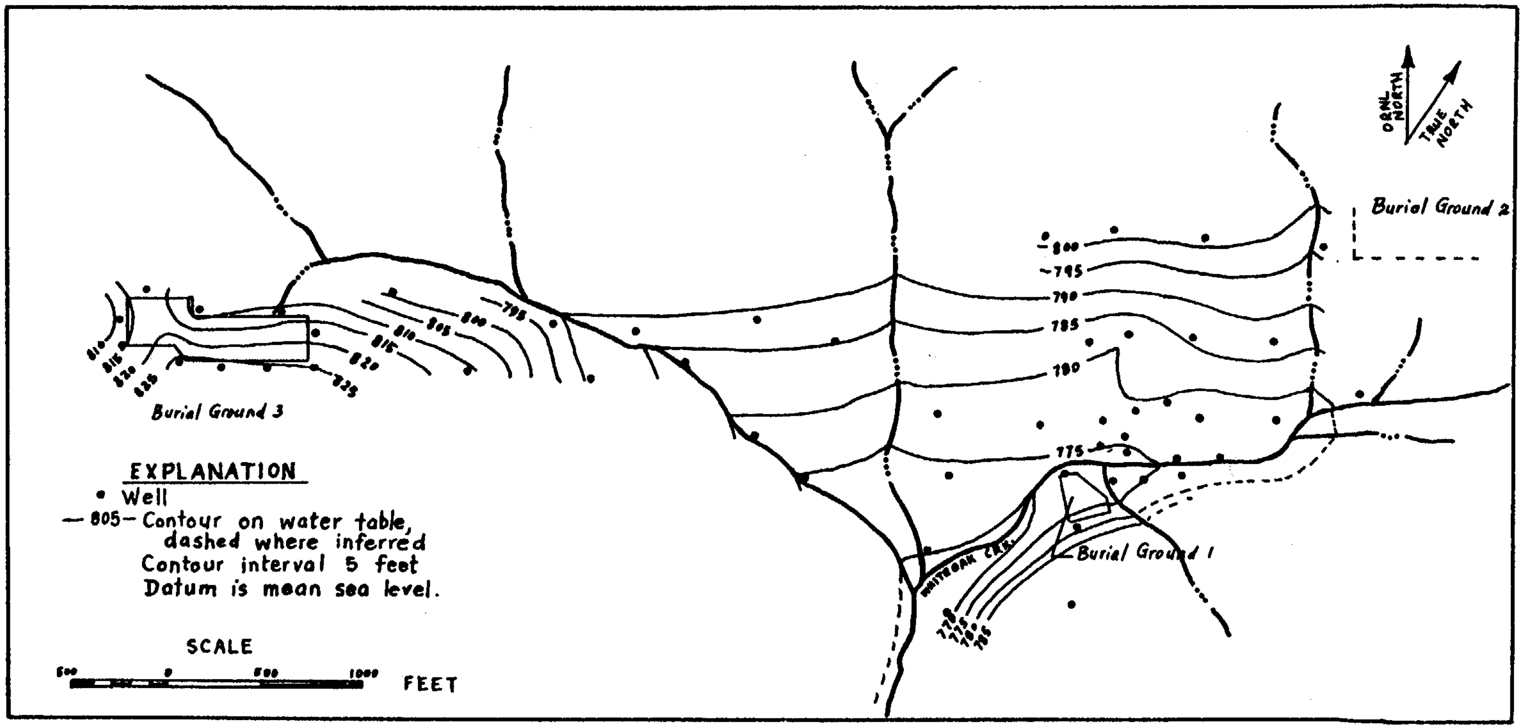

Fig. A.25. Water table map for part of Bethel Valley during June 1950. Note: multiplying feet by 0.305 will convert feet to meters. Source: Webster (1976).

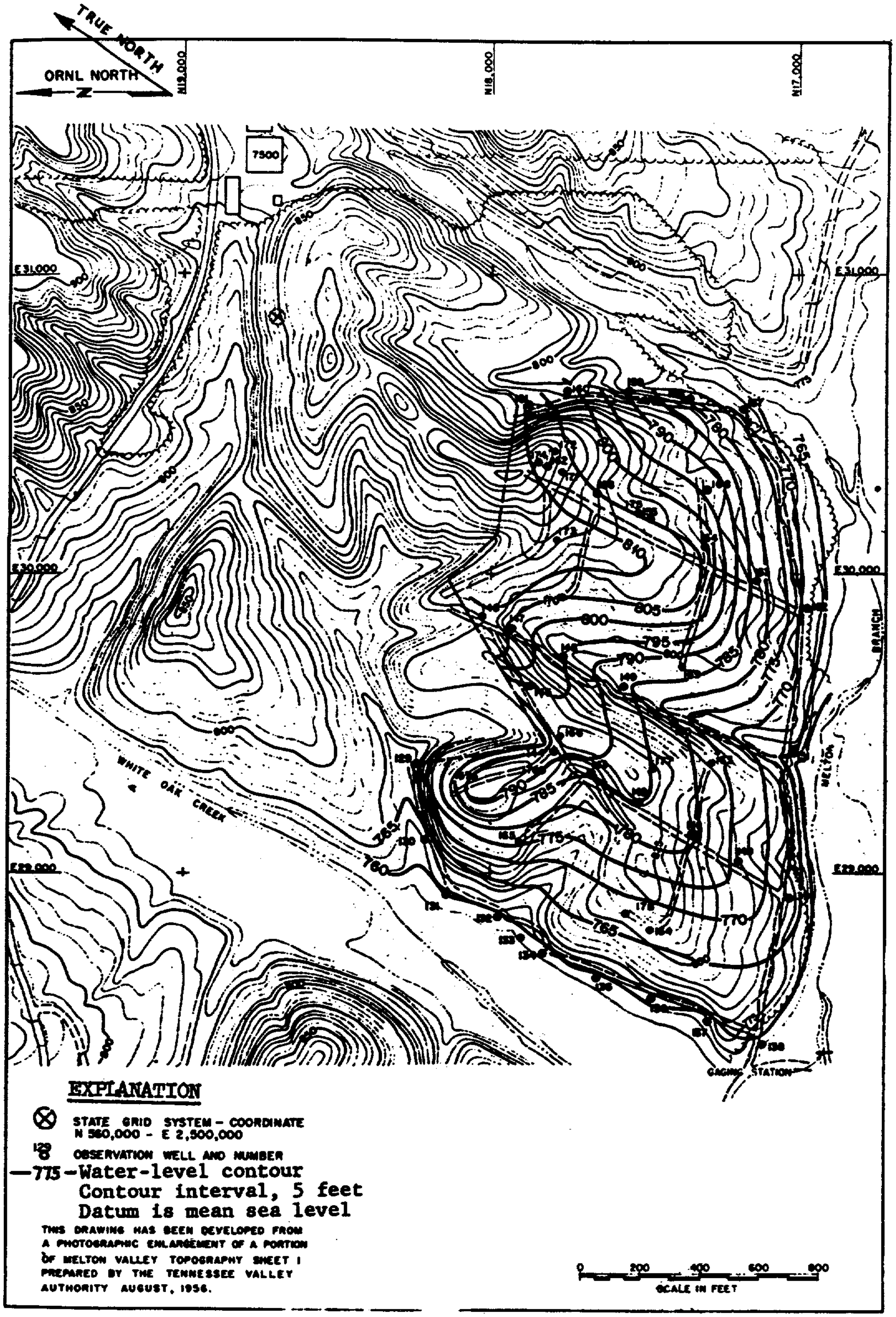

Fig. A.26. Water table map for burial ground 5, December 1959, adapted from Cowser et al. (1961). Note: multiplying feet by 0.305 will convert feet to meters. Source: Webster (1976).

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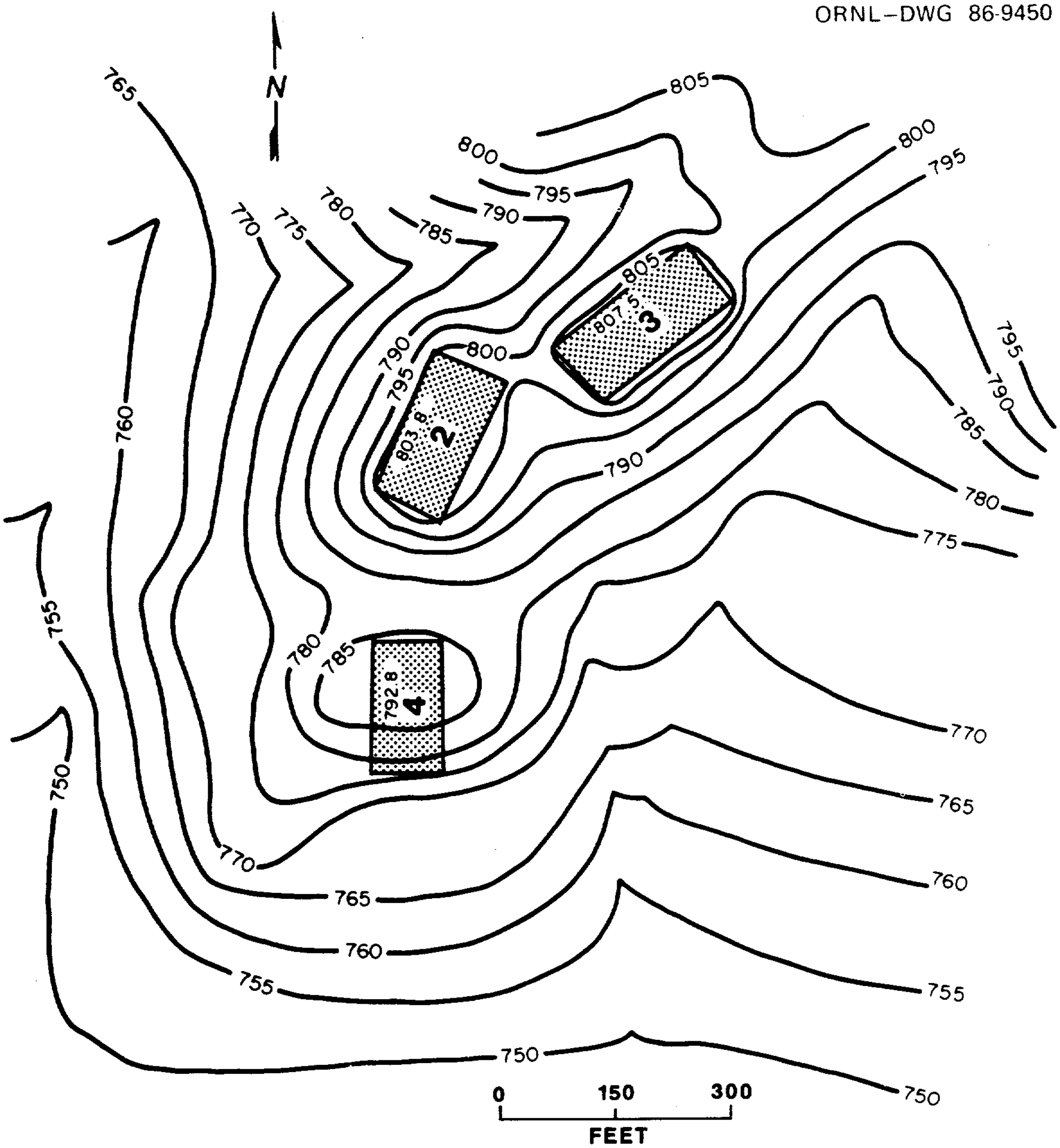

Fig. A.27. Water table contour map for pits and trenches area, January 10, 1958, adapted from DeLaguna et al. (1958).

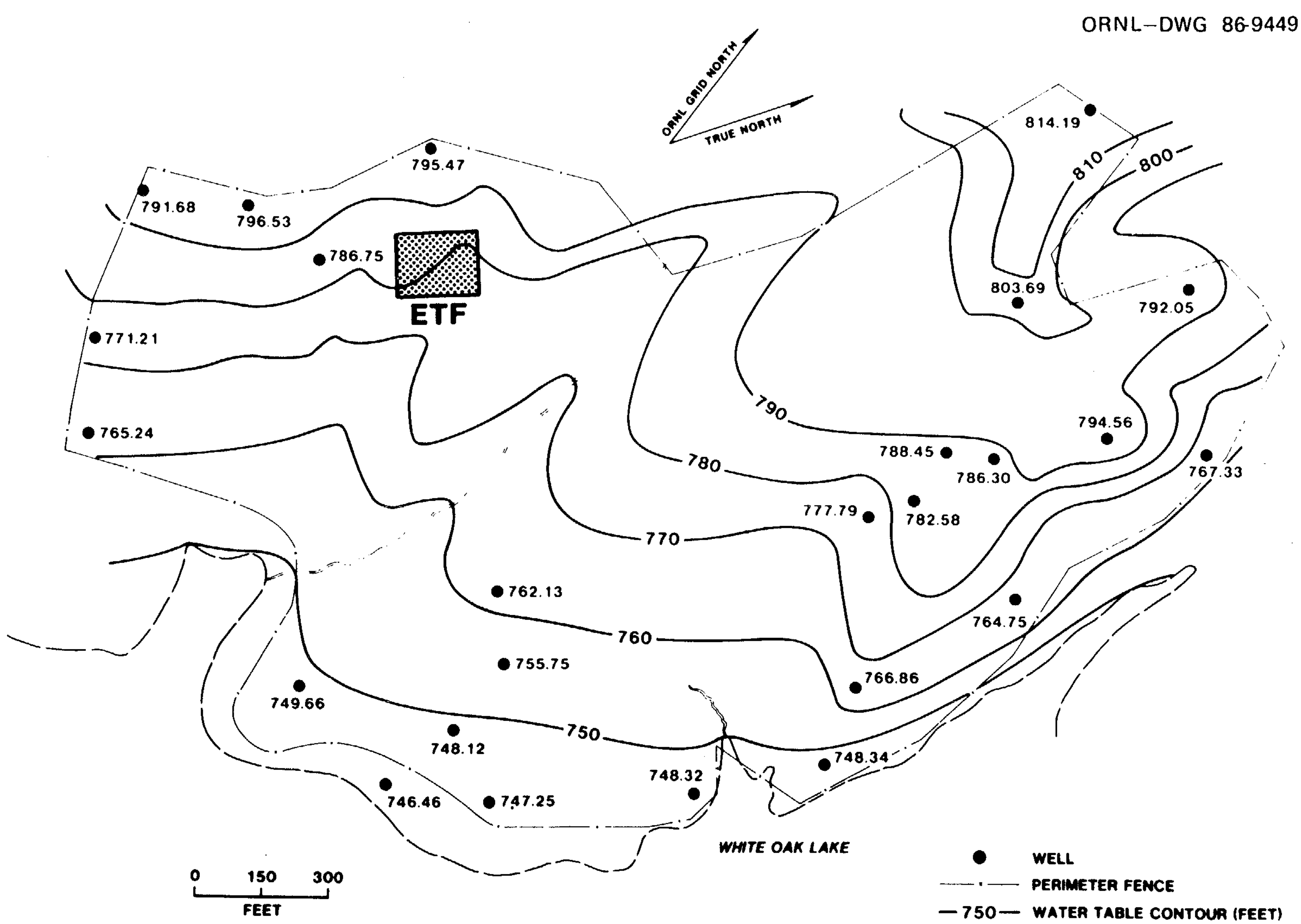

Fig. A.28. Water table map for SWSA-6. Note: multiplying feet by 0.305 will convert feet to meters. Source: Boegly (1984).

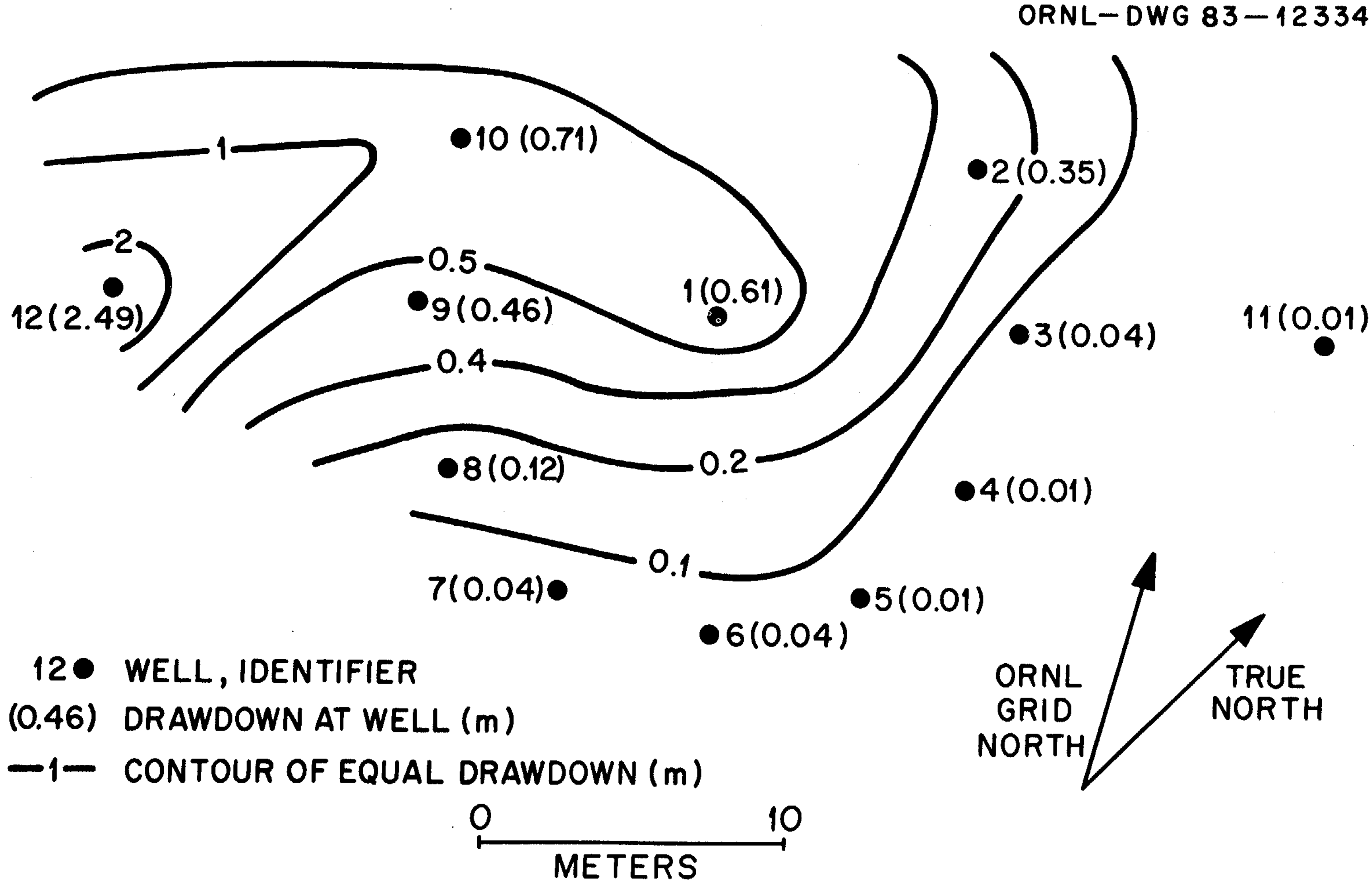

Fig. A.29. Drawdown pattern at the end of the 24-h pumping test in the ETF area of SWSA-6. Source: Davis et al. (1984).

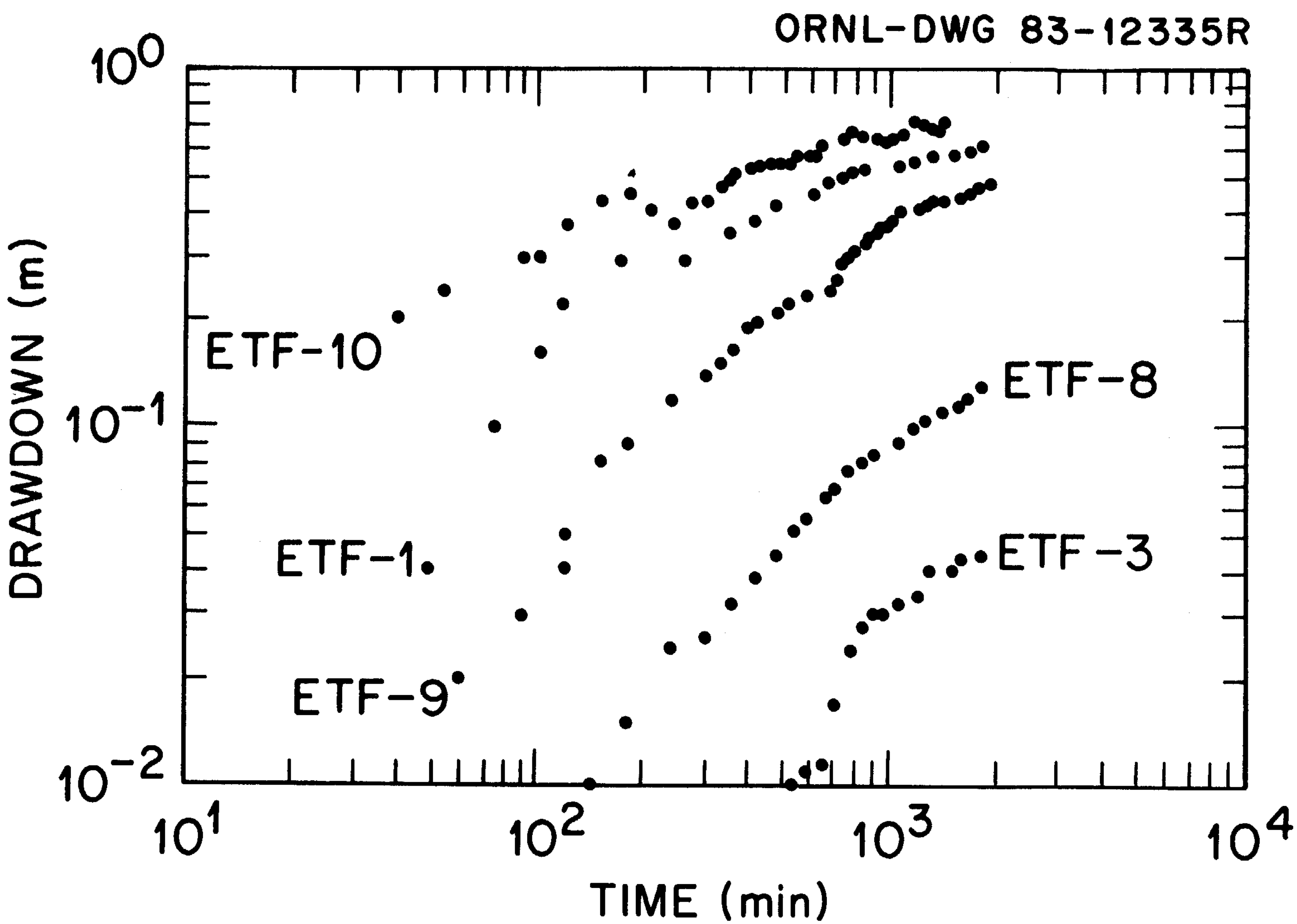

Fig. A.30. Drawdown versus time for wells ETF-1, -3, -8, -9, and -10 during the 24-h aquifer test, June 1, 1982. Source: Davis et al. (1984).

water movement. The curves of drawdown versus time for the wells shown in Figure A.30 were analyzed by a curve matching technique based on the Theis equation (Lohman 1972). Transmissivity (T) (hydraulic conductivity X aquifer thickness) values for the wells shown ranged from 1.25×10^{3} m/min. and averaged 2.54×10^{3} m/min. Storage coefficient(s) (the volume of water an aquifer releases or takes into storage per unit surface area per unit change in head) ranged from 0.01 to 5.12×10^{-4} and averaged about 0.01. Transmissivity values were greatest along geologic strike.

Field tests have been conducted to determine the hydraulic conductivity of the Conasauga in two areas in Melton Valley. Slug tests were conducted in 36 wells in the Engineered Test Facility (ETF) in the SWSA 6 area (Davis et al. 1984) and in 12 wells in the proposed SWSA 7 area (Fig. 2) near the upper reaches of Melton Branch (Rothchild et al. 1984). Slug tests are small scale aquifer tests in which the water level recovery in a well after the instant injection or removal of water is monitored to determine the hydraulic conductivity of the aquifer immediately surrounding the well screen or open interval. The geometric mean of the values determined in the two areas were 6.31×10^{-5} cm/s and 2.57×10^{-5} cm/s respectively. The analysis used to determine hydraulic conductivity is that of Hvorslev (1951). These values are relatively low, but are reasonable for a fractured media (Davis et al. 1984).

Using the mean value for the hydraulic conductivity, 6.31×10^{-5} cm/s and the mean value of the transmissivity (hydraulic conductivity times aquifer thickness), 2.54×10^{-3} m^2/min., an effective aquifer thickness of 67.09 meters was calculated (Davis et al. 1984).

Tracer tests were conducted for aquifer characterization at the ETF site by researchers from Indiana University (Cooper 1981). The tracers were introduced into well ETF1 at a depth of 8.4 m (Fig. A.29). The calculated value of linear velocity was 0.17 m/d, based on the arrival time of the peak concentration of tracer. Using this linear velocity, a measured hydraulic gradient of 0.094 (m/m), and an effective porosity of 0.10, the computed hydraulic conductivity is 0.18 m/d.

Cooper (1981) presented some data that suggested very rapid movement of tracer along the strike joint set. Although it is not possible to define the first arrival of tracer precisely, apparent velocities, based on first arrivals, were of the order of 1 to 2 m/d.

The pattern of tracer arrival at well ETF-3 was attenuated compared with expected migration rates in fractures but was, by far, the largest peak with regard to the mass of tracer. This peak would be expected if flow occurred along the steepest hydraulic gradient (see Figs. A.28 and A.29), suggesting that bulk transport via intergranular flow is probably the significant part of groundwater migration at the ETF. Individual fractures are important and dominate quick movement but are volumetrically less significant than the surrounding media. The intergranular portion of the aquifer at the ETF is most likely a combination of primary porosity and a secondary porosity of very densely spaced and weathered joint system. This joint system is well developed along geologic strike (bedding planes) as well as perpendicular to strike. These tracer tests thus indicate the importance of both rapid migration pathways associated with fractures as well as slower intergranular flow paths that are controlled by the bulk hydraulic properties of the deep residuum and bedrock (Davis et al. 1984).

Davis et al. (1984) used the groundwater velocity (0.17 m/d) and gradient (0.094) from the tracer tests and the mean hydraulic conductivity (6.31×10^{-5} cm/s) with Darcy's Law to calculate a value of 0.03 for the effective porosity of the intergranular media underlying the site.

The summary of the major aquifer characteristics estimated for the ETF site given in Table 5 (Davis et al. 1984) provides a basis for assessing groundwater and solute movement under the ETF site and a general indication of the characteristics of the aquifer underlying the lower WOC watershed. However, detailed aquifer studies will be required in the flood plain of WOC and Lake to determine the aquifer characteristics needed to evaluate groundwater flow in the Conasauga Group underlying the surface drainage system.

A.3.2.3 Chemical Quality. Groundwater at the WOC Watershed is of a calcium bicarbonate type with a pH usually between 7 and 8, reflecting the effects of the limestone and dolomitic materials through which the water has moved (Webster 1976). Radionuclide analyses of water samples from the Engineered Test Facility (ETF) and the proposed SWSA site in Melton Valley are at or near background levels (Davis et al. 1984, Rothchild et al. 1984). Chemical analyses of samples from 12 wells at the ETF site and 18 wells at the proposed SWSA 7 site (Fig. 2) show similar results with calcium as the dominant ion and bicarbonate as the dominant anion. Typical results are shown by the analyses of water collected from a depth of 15.27 meters in well 12 at the ETF site (Table A.23).

Groundwater quality has been greatly affected by contaminants in leachates in the vicinity of solid and liquid waste storage areas or leaks and spills related to laboratory operations; samples from some of the wells in the SWSAs downgradient from the main storage areas and in close proximity to WOC or WOL have been contaminated with a variety of pollutants (Martin Marietta Energy Systems, Inc. 1985). However, the available studies indicate that the migration of leachate in groundwater has been limited to relatively short distances from the source or to nearby seeps or streams. A major part of the drilling and sampling planned for groundwater quality characterization will be conducted in areas downgradient from contaminant sources identified by previous waste storage or spill site studies or by water or sediment sampling in watershed.

Table A.23. Engineered Test Facility Quality: ETF-12

Constituent	Unit	Number of samples	Mean	Standard deviation	Minimum value	Maximum value
Al	mg/L	20	a			
B[b]	mg/L	19	0.055	0.046	0.005	0.136
Br	mg/L	17	a			
Ca	mg/L	20	26.6	5.0	8.9	31.8
Cl	mg/L	20	a			
F	mg/L	20	a			
Fe	mg/L	20	a			
I	mg/L	17	a			
K[b]	mg/L	20	5.18	7.06	0.001	23.0
Mg	mg/L	20	7.18	1.69	2.90	9.9
Mn	mg/L	20	0.013	0.011	0.002	0.040
Na[b]	mg/L	20	3.67	1.50	2.50	6.79
NO_2-N	mg/L	9	a			
NO_3-N	mg/L	20	a			
P (total)	mg/L	16	a			
PO_4-P	mg/L	10	a			
SiO_2	mg/L	19	13.45	2.05	9.80	16.00
SO_4[b]	mg/L	20	10.8	2.4	4.0	14.0
Sr[b]	mg/L	19	0.124	0.025	0.044	0.152
Total alkalinity	mg/L as $CaCO_3$	19	106	8	76	113
Conductivity	µS/cm	19	157	48	118	300
pH	pH units	19	7.7	0.9	7.0	11.0
TOC	mg/L	2	2.2	1.8	0.9	3.5
Tritium[b]	Bq/L[b]	5	19	16	2	37
^{90}Sr[b]	Bq/L	5	1.03	0.96	0.02	2.0
Gross alpha	Bq/L	5	0.39	0.34	0.11	0.90
^{137}Cs	Bq/L	5	a			
^{60}Co	Bq/L	5	a			

[a]Majority of values below detection limit; therefore, no mean is reported.
[b]Majority of values above detection limit; therefore, mean = maximum mean.

Source: Davis et al. 1984.

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